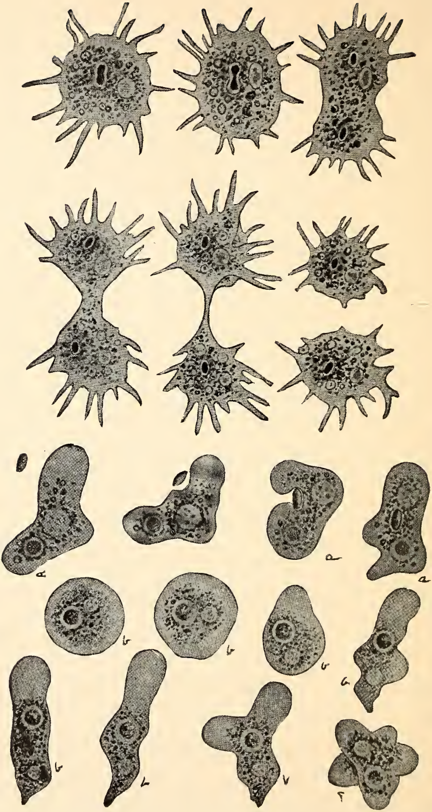

Multiplication of Amœba by Simple Fission. Shapes Assumed by Amœba When Moving.

THE SCIENCE - HISTORY OF THE UNIVERSE

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THE
SCIENCE-HISTORY OF THE UNIVERSE

VOLUME V

BIOLOGY

By CAROLINE E. STACKPOLE

CONTENTS

BIOLOGY

CHAPTER I

BIOLOGY: THE SCIENCE OF LIFE

Life, that strange, mysterious, unknown something which flies through the viewless air, flashes through the ocean's depths, blushes in the petals of a rose and manifests itself in a thousand marvelous forms—can science grasp, define or explain it? Death, that wondrous change which sooner or later stills the activities of all forms of life and returns them to the realm of the lifeless—what is its nature? Why is it necessary? Can science understand or control it? These inquiries and others like them which have troubled the human mind in all ages are the fundamental problems of the science of life.

With the dawn of human consciousness there must have come the realization that this is an earth with two worlds—the living and the lifeless. The progress of the ages has not lessened the contrast; and to-day, men of science, recognising the great chasm between life and death, between the living and the lifeless on the earth, are compelled to group the natural sciences into the Biological Sciences dealing with living things or organisms; and the Abiological Sciences, or Physical Sciences, dealing with lifeless matter. The biological sciences are known collectively as biology, which is therefore often defined as the science of life, of living things, or of living matter. "But living matter," say Sedgwick and Wilson in their 'General Biology,' "is only ordinary matter which has en-

tered into a peculiar state or condition. And hence biology is more precisely defined as the science which treats of matter in the living state."

If the term biology be used in its widest sense of Life-lore to include all the results of the scientific study of living creatures, it may be said to have had its foundations in antiquity. But if the term is restricted to the use as defined above—that is, to the study of the vital phenomena common to both plants and animals—it is quite modern.

Biology is not a new name for the older science known as Natural History, nor is it, as is often thought, a combination of botany and zoölogy, it is rather a unified science of life. Taken in this sense, the science has been in existence but little more than a hundred years. The history of its development is the history of the splitting up of the Natural History of earlier times into the separate sciences known to-day, physics, chemistry, botany, zoölogy, etc.; a recognition of the essential similarity of the vital functions of all living things, plants or animals; and the development of a separate science for the study of these phenomena. Huxley, in his essay "On the Study of Biology," writes of its history in these words:

"At the revival of learning, knowledge was divided into two kinds—the knowledge of nature and the knowledge of man; for it was the current idea then—and a great deal of that ancient conception still remains—that there was a sort of essential antithesis, not to say antagonism, between nature and man; and that the two had not very much to do with one another, except that the one was oftentimes exceedingly troublesome to the other. Tho it is one of the salient merits of our great philosophers of the seventeenth century, that they recognised but one scientific method, applicable alike to man and to nature, we find this notion of the existence of a broad distinction between nature and man in the writings both of Francis Bacon and of Thomas Hobbes. Hobbes says: 'The register of knowledge of fact is called history. Whereof there be two

sorts, one called natural history; which is the history of such facts or effects of nature as have no dependence on man's will; such as are the histories of metals, plants, animals, regions and the like. The other is civil history; which is the history of the voluntary actions of men in commonwealths.'"

Thus all history of fact was divided into these two great groups of natural and of civil history. As time went on, and the various branches of human knowledge became more distinctly developed and separated from one another, it was found that some were much more susceptible of precise mathematical treatment than others. The publication of the "Principia" of Newton showed that precise mathematical methods were applicable to those branches of science such as astronomy, and what is now called physics, which occupy a very large portion of the domain of what the older writers understood by natural history.

Time went on, and yet other branches of science developed themselves. Chemistry took a definite shape; and since all these sciences, such as astronomy, natural philosophy and chemistry, were susceptible either of mathematical treatment or of experimental treatment, or of both, a broad distinction was drawn between the experimental branches of what had previously been called natural history and the observational branches—those in which experiment was (or seemed) of doubtful use, and where, at that time, mathematical methods were inapplicable.

Under these circumstances the old name of "Natural History" stuck by the residuum of those phenomena which were not, at that time, susceptible of mathematical or experimental treatment; that is to say, those phenomena of nature which come now under the general heads of physical geography, geology, mineralogy, the history of plants, and the history of animals. It was in this sense that the term was understood by the great writers of the middle of the last century, Buffon and Linnaeus, by Buffon in his great work, the 'Histoire Naturelle Générale,' and by

Linnaeus in his splendid achievement, the "Systema Naturae." The subjects they deal with are spoken of as "Natural History," and they called themselves and were called "Naturalists." It is clear that such was not the original meaning of these terms; but that they had by this time, acquired a signification widely different from that which they possessed primitively.

Despite the marvelous progress made by science at the latter end of the eighteenth and the beginning of the nineteenth century, thinking men began to discern that under this title of "Natural History" there were included very heterogeneous constituents. For example, it was not hard to see that geology and mineralogy were, in many respects, widely different from botany and zoölogy; that a man might obtain an extensive knowledge of the structure and functions of plants and animals without having need to enter upon the study of geology or mineralogy, and vice versa; and, further as knowledge advanced, it became clearer that there was a great analogy, a very close alliance, between those two sciences, of botany and zoölogy, which deal with living beings, while they are much more widely separated from all other studies. Therefore, it is not wonderful that, at the beginning of the nineteenth century, in two different countries, and apparently without any intercommunication, two famous men clearly conceived the notion of uniting the sciences which deal with living matter into one whole, and of dealing with them as one discipline.

In fact, there were three men to whom this idea occurred contemporaneously, altho but two who carried it into effect, and only one who worked it out completely. These persons were the eminent physiologist Bichat; the great naturalist Lamarck, in France, and a distinguished German, Treviranus. Bichat assumed the existence of a special group of "physiological" sciences. Lamarck, in a work published in 1801, for the first time made use of the name "Biologie," from the two Greek words which signify

a discourse upon life and living things. About the same time it occurred to Treviranus, that all those sciences which deal with living matter were essentially and fundamentally one, and ought to be treated as a whole; and, in the year 1802, he published the first volume of what he also called "Biologie." Treviranus's great merit lies in this, that he carried out his idea, and wrote the very remarkable work above mentioned. It consists of six volumes, and occupied its author for twenty years—from 1802 to 1822. That is the origin of the term "Biology," which denotes the whole of the sciences which deal with living things, whether they be animals or whether they be plants.

After discussing the origin of the science of biology, the next questions that naturally present themselves are with reference to the extent and nature of its scope. In its strict technical sense, Biology denotes all the phenomena which are exhibited by living things, as distinguished from those which are not living; but while that secondary definition suffices in the domain of the lower animals and plants, it is found to involve considerable difficulties in an investigation of the higher forms of living things. For whatever views may be entertained about the nature of man, one thing is perfectly certain, that he is to be considered a living creature. Hence, a strict interpretation of such a definition must include man and all his ways and works under the head of biology; in which case, psychology, politics, and political economy would be absorbed into the province of Biology.

It has been found convenient to set human psychology and sociology apart from biology, but the progress of these sciences in the past century has clearly shown that they are intrinsically inseparable from biology or that they at least find many of their fundamental principles in the general science of life.

Even without the psychological and sociological phases of human life, the field covered by biology as thus under-

stood is so wide as to necessitate a subdivision of the subject into a number of branches, to which are usually assigned the rank of distinct sciences. As already pointed out, the usual division of biology into botany and zoölogy has the great advantage of practical convenience, since, as a matter of fact, most biologists devote their attention mainly either to plants alone, or to animals alone. From a scientific point of view, however, a better subdivision is into Morphology and Physiology. The former is based upon the facts of form, structure and arrangement, and is essentially statical; the latter upon those of action or function, and is essentially dynamical. But morphology and physiology are so intimately related that it is impossible to separate either subject absolutely from the other, for which reason authors speak of plant morphology and animal morphology, plant physiology and animal physiology.

There are further subdivisions. Thus on the plant or animal side of biology there are the following subsciences: Anatomy—the science of structure, the term being usually applied to the coarser and more obvious composition of plants or animals; Histology—microscopical anatomy, the ultimate analysis of structure by the aid of the microscope, separated from anatomy only as a matter of convenience; Taxonomy—the classification of living things, based chiefly on the phenomena of structure; Distribution—considering the position of living things in space and time, their distribution over the present face of the earth and their distribution and succession at former periods, as displayed in fossil remains; Embryology—the science of development from the germ, including many problems pertaining both to morphology and physiology; and Physiology (including pathology)—the special science of the functions of the individual in health and in disease. The very highly specialized biological sciences, ornithology (birds), entomology (insects), herpetology (reptiles), conchology (shells), lichenology (lichens), bryology (mosses), mycology (fungi), etc., apply to the groups of

animals and plants indicated by the names of these sciences. They are chiefly concerned with classification and hence deal largely with details of structure.

While the scope of biology may be thus skeletonized, it must be pointed out with emphasis that the common conception of biology as simply a combination of botany and zoölogy is one which tho convenient and indeed necessary for practical purposes, and for extended study and research, does not concern the present treatment. Dealing with organic structures and functions in connection with their causes, conditions, concomitants and consequences, Biology cannot divide itself into Animal Biology and Vegetable Biology; since the same fundamental classes of phenomena are common to both. It is with these general vital phenomena common to both plants and animals that this work is concerned, hence in considering the general problems of the science of biology the familiar division into botany and zoölogy is recognised only occasionally as a matter of convenience. Undoubtedly confusion will be avoided if it is kept in mind that 'General Biology' is the subject under view. This term does not designate a particular member of the group of biological sciences, "but is only a convenient phrase, which has recently come into use for the general introductory study of biology. It includes a description of the general properties of living matter as revealed in the structures and actions of living things, and may serve as the basis for subsequent study of more special branches of the science. It deals with the broad characteristic phenomena and laws of life as they are illustrated by the thoro comparative study of a series of plants and animals taken as representative types; but inasmuch as all the varied phenomena which come under observation are in the last analysis due to the properties of matter in the living state, the biologist ever remembers that this matter and these properties are the goal of study."

CHAPTER II

THE NATURE OF LIFE

More puzzling than the riddle propounded by the fabled Sphynx is the problem suggested by the title of this chapter. "What is life?" is a question which has been asked by the scholars of all ages and man to-day is no nearer a final answer than were the philosophers in the earliest centuries of the historic era. Modern science has vastly extended knowledge of the phenomena which are called vital but has failed to tell what life is. Thus according to Herbert Spencer's so-called proximate definition, which of the many definitions of life has attracted most attention, life is the continuous adjustment of internal relations to external relations. This definition Spencer has explained as follows:

"All vital actions, considered not separately but in their ensemble, have for their final purpose the balancing of certain outer processes by certain inner processes. There are unceasing external forces tending to bring the matter of which organic bodies consist, into that state of stable equilibrium displayed by inorganic bodies; there are internal forces by which this tendency is constantly antagonized, and the perpetual changes which constitute Life may be regarded as incidental to the maintenance of the antagonism. To preserve the erect posture, for instance, we see that certain weights have to be neutralized by certain strains: each limb or other organ, gravitating to the Earth and pulling down the parts to which it is attached,

has to be preserved in position by the tension of sundry muscles; or in other words, the group of forces which would if allowed bring the body to the ground, has to be counterbalanced by another group of forces. Again, to keep up the temperature at a particular point, the external process of radiation and absorption of heat by the surrounding medium, must be met by a corresponding internal process of chemical combination, whereby more heat may be evolved; to which add, that if from atmospheric changes the loss becomes greater or less, the production must become greater or less. And similarly throughout the organic actions in general.

"When we contemplate the lower kinds of life, we see that the correspondences thus maintained are direct and simple; as in a plant, the vitality of which mainly consists in osmotic and chemical actions responding to the coexistence of light, heat, water and carbonic acid around it. But in animals, and especially in the higher orders of them, the correspondences become extremely complex. Materials for growth and repair not being, like those which plants require, everywhere present, but being widely dispersed and under special forms, have to be found, to be secured, and to be reduced to a fit state for assimilation. Hence the need for locomotion; hence the need for the senses; hence the need for prehensile and destructive appliances; hence the need for an elaborate digestive apparatus.

"Observe, however, that these successive complications are essentially nothing but aids to the maintenance of the organic balance in its integrity, in opposition to those physical, chemical and other agencies which tend to overturn it. And observe, moreover, that while these successive complications subserve this fundamental adaptation of inner to outer actions, they are themselves nothing else but further adaptations of inner to outer actions. For what are those movements by which a predatory creature pursues its prey, or by which its prey seeks to escape, but certain changes in the organism fitted to meet certain

changes in its environment? What is that compound operation which constitutes the perception of a piece of food, but a particular correlation of nervous modifications, answering to a particular correlation of physical properties? What is that process by which food when swallowed is reduced to a fit form for assimilation, but a set of mechanical and chemical actions which distinguish the food? Whence it becomes manifest, that while Life in its simplest form is the correspondence of certain inner physico-chemical actions with certain outer physico-chemical actions, each advance to a higher form of life consists in a better preservation of this primary correspondence by the establishment of other correspondences.

"Divesting this conception of all superfluities and reducing it to its most abstract shape, we see that Life is definable as the continuous adjustment of internal relations to external relations."

It is clear that this definition in the last analysis is but a general statement of the fundamental vital relations existing between living matter and lifeless phenomena. It does not really define life. Other authors have done no better, in fact their definitions have been less inclusive. But aside from attempts at forming abstract definitions of life there are some significant considerations regarding living matter which have been important in the development of knowledge of the differences between the living and the lifeless and of the working of the mechanism of life.

The living and the lifeless present a fundamental contrast. "If the development of the conception of life be followed back," says Verworn, "when mankind had no presentiments of all the occupations that accompany a highly developed culture, when he was unacquainted with fire, when he did not know how to make even the most primitive tools, the conclusion is reached that the conception sprang from the combination of a number of simple phenomena, which early man discovered by self-observation,

especially those phenomena that are associated with evident movements, such as locomotion, breathing, nutrition, the heartbeat and others. In fact, it is not difficult to analyze into their primary constituents the complex occupations of our present life, and to recognise that its diversity is produced by various combinations of a few elementary phenomena, such as nutrition, respiration, growth, reproduction, movement and the production of heat."

It must be remembered, however, that such a conception of life is limited to the vital phenomena of human beings, while the field of life is far greater. Animals and plants likewise exhibit vital phenomena, and it may be asked whether these latter are the same as or different from the phenomena that prevail among men. It is evident that all living organisms must be included in the sphere of physiological investigation, the flower and the worm equally with man. Hence the first duty of physiology is to mark out the field of the living, to determine what is living and what is not living—an undertaking that is more difficult than it appears.

The conception of life has not always been the same. It has experienced fundamental changes in the course of the development of the human species. Formed first with respect to mankind, it was early extended to other objects. With primitive races, the conception was much wider than at present, and they termed living what is no longer regarded as such. With them stars, fire, wind and waves were beings endowed with life and mind, and they were personified in the image of man. The remains of these ideas are still found in the mythology of the classic and modern races. In the course of time the distinction between living and lifeless has been made constantly sharper, but even to-day a child regards a steam engine as a living animal. The child is guided more or less consciously by the same criterion as the primitive races, who, from the fact of motion, considered as living the dancing

flame of a fire or a moving wave. In fact, of all vital phenomena, motion is that which gives most strongly the impression of living.

It may be said that only primitive races and children are misled by the criterion of motion, and that the civilized and adult man, who is versed in a knowledge of life, is capable of deciding easily in any given case between the living and the lifeless. But this is not always true. For example, are dried grains living or lifeless? Is a lentil that has lain unchanged in a chest for years living? Scientific men themselves are not agreed upon this point. The lentil, when dry, does not show phenomena of life, but, if placed in moist earth, it can at any moment be induced to do so. It then sprouts and grows into a plant.

The decision between the living and the lifeless becomes, however, much more difficult with objects that are not commonly seen in daily life—*e.g.,* certain microscopic things. Long observation and very detailed investigation are frequently required in order to determine whether certain bodies that are found in a liquid by microscopic examination are living or not. If a drop of the dregs be taken from a bottle of weissbeer and examined with the microscope, it will be found that the liquid contains innumerable small pale globules, often clinging together in groups of two or three, completely at rest so long as they are observed, and showing no trace of movement or other change. Very similar small globules may be observed with a microscope in a drop of milk. The two kinds of globules can be distinguished from one another by strong magnifying powers only.

No trace of vital phenomena can be found in either by the most patient and continued microscopic examination, yet the two objects are as widely different as a living organism and a lifeless substance; for the globules from the beer are the so-called yeast-cells, the active agent in the fermentation of the beer, and are fully developed, unicellular, living organisms, while the globules from the

milk are lifeless droplets of fat, which, by their abundant presence and their reflection of light from all sides, give to the milk its white color. The manifestation of motion, which is often ascribed to an internal source because no external source is directly visible, thus frequently misleads to the assumption of life.

Hence, under certain circumstances it is not at all easy to distinguish the living from the lifeless, and it is accordingly clear that the first duty of physiology must be to inquire after the criteria of such a distinction—*i.e.*, mentally to circumscribe the subject-matter, life, in relation to non-living nature.

The distinction between living and lifeless matter is made still more complicated by the fact that the living substance of the human body, or of any animal or plant, is only the transformed lifeless matter of the food which has been taken into the body and has there assumed, for a time, the living state. Lifeless matter in the shape of food is continually streaming into all living things on the one hand and passing out again as waste on the other. In its journey through the organism some of this matter enters into the living state and lingers for a time as part of the bodily substance. But sooner or later it dies, and is then for the most part cast out of the body (tho a part may be retained within it, either as an accumulation of waste material, or to serve some useful purpose). Matter may thus pass from the lifeless into the living state and back again to the lifeless, over and over in never-ending cycles. A living plant or animal is like a whirlpool into which, and out of which, matter is constantly streaming, while the whirlpool maintains its characteristic form and individuality.

"To put the matter in the most general shape," says Huxley, "the body of the organism is a sort of focus to which certain material particles converge, in which they move for a time, and from which they are afterward expelled in new combinations. The parallel between a

whirlpool in a stream and a living being, which has often been drawn, is just as it is striking. The whirlpool is permanent, but the particles of water which constitute it are incessantly changing. Those which enter it on the one side are whirled around and temporarily constitute a part of its individuality; and as they leave it on the other side, their places are made good by newcomers.

"Those who have seen the wonderful whirlpool, three miles below the Falls of Niagara, will not have forgotten the heaped-up wave which tumbles and tosses, a very embodiment of restless energy, where the swift stream hurrying from the Falls is compelled to make a sudden turn toward Lake Ontario. However changeful in the contour of its crest, this wave has been visible, approximately in the same place and with the same general form, for centuries past. Seen from a mile off, it would appear to be a stationary hillock of water. Viewed closely it is a typical expression of the conflicting impulses generated by a swift rush of material particles.

"Now, with all our appliances, we cannot get with a good many miles, so to speak, of the living organism. If we could, we should see that it was nothing but the constant form of a similar turmoil of material molecules, which are constantly flowing into the organism on the one side and streaming out on the other."

What are the distinctive properties of living matter as contrasted with lifeless matter? What are the elementary vital phenomena? The composition of living substance has long been supposed to hold the key to the mysteries of life manifestations. The ancients naïvely believed that they were able to explain the substance of living bodies by the intermixture of certain materials. Thus, Hippocrates believed that the normal human body consists of blood, phlegm and bile, which are mixed together in certain proportions. In the middle ages, when people endeavored to solve the riddle of nature by the great power of alchemy, they thought that they were upon the track

of the secret of living substance. How strong this delusion was is shown by the many attempts of the middle ages to produce living substance artificially.

The ardent expectation with which the medieval alchemist in the somber dusk of his laboratory, surrounded by skilled workers and strange apparatus, hoped every moment to see the homunculus arise complete from the retorts or crucibles is a very characteristic feature of the developmental stage of science during these centuries. But, however proud moderns may be of the advancement of science, they have no right to look with scorn upon those attempts of the middle ages, when it is realized that from that time even to the most recent period the attempts have been continued to produce artificially not man himself, but the simplest forms of living substance. Yet all these attempts resemble the endeavor of a man to put together a complicated clock-work without knowing its essential parts.

"However simple the problem of the artificial production of living substance appeared to the middle ages," says Verworn, "the progress of sober thought and critical investigation has shown constantly how far we are yet from a knowledge of the intimate composition of such substance. How is it possible to produce chemically a substance the chemical composition of which is not at all known? Modern research has been directed, therefore, more and more toward an examination of the composition of living substance. It has penetrated deeply, and continues to penetrate, into the morphological, physical and chemical relations, and the intimate structure of living matter."

Altho this accumulated knowledge concerning the composition of living matter does not distinguish between the living and the lifeless, it has given many interesting facts concerning the properties of living matter. In its physical properties living matter in animal and plant tissues behaves like a liquid. The idea that vital phenomena can be asso-

ciated with a solid substratum only is not only unjustified, but even untenable. Not only is it unsupported on any acceptable ground, but it even contradicts facts that may easily be observed. It is quite impossible to understand how protoplasm in the more or less stiff condition of a framework or network can be capable of streaming and flowing as can be observed so easily in certain plant-cells and in Amoeba. It is impossible for a solid network to flow in such a manner that the individual particles of its mass mix continually with one another, as may be seen so clearly in Amoeba. If at first sight the theory of the solid consistency may not be incompatible with the behavior of cells that possess a constant form, it is absolutely so with the phenomena exhibited by naked protoplasmic masses. Hence various investigators, especially Berthold and Bütschli, have recently defended strongly the idea of the liquid nature of the cell-contents, and no investigator who is familiar with the phenomena need hesitate to accept this view.

Living matter has a greater density than water. That some animals and plants float is due to the accumulation in their tissues of certain lifeless matters such as fat and gasses, which diminish their specific gravity.

In chemical structure the differences between living and lifeless matter, altho not distinctive, are of importance. Only twelve elements are found constantly in living matter: carbon, nitrogen, sulphur, hydrogen, oxygen, phosphorus, chlorine, potassium, sodium, magnesium, calcium and iron. A few others, silicon, fluorine, bromine, iodine, aluminium and manganese are found occasionally. But all these elements are also found in the lifeless matter composing the air, water and the surface of the earth.

Since the chemical analysis of living substance has shown that no constituents but these organic elements are to be found in the organism, the important fact follows that an elementary vital substance exists no more than a specific vital force. The conception of a "vital ether,"

a "spiritus animalis," a "vital matter," etc., with which the earlier physiology so freely dealt, have, therefore, in harmony with the advanced development which analytical chemistry has undergone at the present time, completely disappeared from the present theory of life; living substance is composed of no different chemical materials from those occurring within lifeless bodies.

Nevertheless, one fact deserves mention, viz., that the few general organic elements are not scattered irregularly here and there through the natural system of elements, but they occupy a definite position, being remarkable as elements having very low atomic weights. "Hence," writes Verworn, "the conclusion may with great probability be drawn that in the evolution of the elements the organic elements arose by condensation very early, and therefore existed in the very early stages of the development of our planetary system, at a time when other elements, such as the heavy metals, had not yet been formed."

Following the discovery that living matter contains no distinctive chemical elements, physiological chemists turned their attention to the search for specific chemical compounds. Here the investigation is most difficult. It is not possible to apply the methods of chemistry to living substance without killing it. Every chemical reagent that comes in contact with it disturbs it and changes it, and what is left for investigation is no longer living substance, but a corpse—a substance that has wholly different properties. Hence ideas upon the chemistry of the living object can be obtained only by deductions from chemical discoveries in the dead object, deductions the correctness of which can be proved experimentally in the living object only in rare cases.

This alone is responsible for the excessively slow advance of the knowledge of the chemistry of the vital process. It is evident that the greatest foresight is necessary in applying results obtained upon the dead object to conditions in the living, and it must constantly be borne in

mind that the chemical relations of the latter are to be distinguished sharply from those of the former.

Altho there is no fundamental difference between the elements composing living and those composing lifeless substance, in other words, altho no special vital element exists in the organic world, some of the elements in living substance form unique compounds which characterize it only, and are never found in lifeless substance. Thus, there exist in the former, besides chemical compounds that occur also in the latter, specific organic complexes of atoms. Many of these organic compounds, especially those that are of special importance to living substance, possess so complicated a constitution that thus far chemistry has not succeeded in obtaining an insight into the spatial relations of the atoms in their molecules, altho the percentage composition of the molecules is known to a greater extent.

There are especially three chief groups of chemical bodies and their transformation-products, by the presence of which living substance is distinguished from lifeless substance; these are proteids, fats and carbohydrates. Of these only the proteids and their derivatives have been demonstrated with certainty as common to all cells; hence they must be set apart among the organic constituents of living matter as the essential or general substances, in contrast to all special substances.

It is not, however, the mere presence of proteids which is characteristic of living matter. White of egg (albumen) contains an abundance of a typical proteid and yet is absolutely lifeless. Living matter does not simply contain proteids, but has the power to manufacture them out of other substances; and this is a property of living matter exclusively. While the other organic compounds—carbohydrates, fats and some simpler substances—have not been found in all living matter, it is a significant fact that they are derived from proteids and are necessary to the construction of proteids.

But even the presence of the so-called organic com-

pounds—proteids, carbohydrates and fats—is an uncertain distinction between the living and the lifeless, for chemistry is rapidly breaking down the supposed barrier between the organic and the inorganic. Each year records new synthetic combinations of compounds supposed to be produced by living matter. Who knows when even the proteid molecule may yield its secret to some synthetic chemist?

Thus the conclusion is reached, strange at first sight, that the matter constituting the living world is identical with that which forms the inorganic world. "And not less true," says Huxley, "is it that, remarkable as are the powers, or, in other words, as are the forces which are exerted by living beings, yet all these forces are either identical with those which exist in the inorganic world, or they are convertible into them. I mean in just the same sense as the researches of physical philosophers have shown that heat is convertible into electricity, that electricity is convertible into magnetism, magnetism into mechanical force or chemical force, and any one of them into the other, each being measurable in terms of the other—even so, I say that great law is applicable to the living world."

The composition of living matter as known in modern chemistry then does not satisfactorily distinguish between living and lifeless matter, and the question, what is the characteristic difference? again forces itself to the center of attention. The generally accepted answer is that this difference is to be found in certain powers or properties of living matter. These are the power of waste, repair and growth and the power of reproduction. "Living matter," to quote from Sedgwick and Wilson, "is continually wasting away by a kind of internal combustion, but continually repairs the waste by the process of growth. Moreover, this growth is of a characteristic kind, differing absolutely from the so-called growth of lifeless things. Crystals and other lifeless bodies grow, if at all, by accre-

tion, or the addition of new particles to the outside. Living matter grows from within by intussusception, or taking in new particles, and fitting them into the interstices between those already present, throughout the whole mass. And lastly, living matter not only thus repairs its own waste, but also gives rise by reproduction to new masses of living matter which become detached from the parent mass and enter forthwith upon an independent existence.

"We may perceive how extraordinary these properties are by supposing a locomotive engine to possess like powers: to carry on a process of self-repair in order to compensate for wear, to grow and increase in size, detaching from itself at intervals pieces of brass or iron endowed with the power of growing up step by step into other locomotives capable of running themselves, and of reproducing new locomotives in their turn. Precisely these things are done by every living thing, and nothing in any degree comparable with them takes place in the lifeless world."

In connection with the foregoing it should be noted that some modern authors, notably Verworn, hold that even metabolism (the power of waste, repair and growth) does not constitute a fundamental contrast between living organisms and inorganic bodies. For example, there are rare cases known to chemists in which simple chemical compounds under certain conditions undergo a regular succession of destructions and constructions, always with the gain or loss of substances which correspond in principle to the continued streaming of matter through the constructive and destructive changes in the metabolism of living substances. Metabolism, then, cannot be said to be absolutely distinctive, as a general principle, of living matter, but practically the metabolism of proteid which is found in nature only in organic bodies, is sufficiently distinctive of living matter. The discovery of apparently analogous processes in inorganic substances simply suggests that the chemical changes concerned in the powers

or activities of living matter are subject to the same fundamental laws as govern change in lifeless matter.

Certain critical physiologists have pointed out that reproduction is not absolutely distinctive. It is true that in higher organisms in which reproduction involves development of eggs, seeds or germs, reproduction is absolutely incomparable with any process in lifeless matter, but many microscopic organisms reproduce by simple division without development, and such simple reproduction is not far removed from similar changes which may occur in lifeless matter. But here again these are really only suggestions of similarity between living and lifeless processes. To most present-day biologists the known facts of reproduction, like those of metabolism, are not in any scientific sense paralleled by processes occurring in inorganic matter.

Finally, even the method of growth by intussusception of particles has been said to offer no criterion of distinction, for liquids (and living matter is liquid) grow by intussusception. However, this strikes many biologists as a mere quibble with words, for growth by intussusception in organisms involves other changes—*e.g.*, foods not proteids may be the material for growth of plant proteid, and plant proteid may in turn serve as food for growth and give rise to animal proteid.

Such critical comparisons suggesting that metabolism, growth and reproduction are not entirely absent from lifeless matter are interesting, but in the present state of scientific knowledge the processes involved in waste, repair, growth and reproduction are to be considered strikingly characteristic of living matter. These are probably complications of simple chemico-physical processes, some of which suggest similarity between living and lifeless matter, but the very complexity of the metabolic and reproductive processes in living forms is distinctive. A parallel case is that of proteid of which, as has been stated, the most distinctive feature is the complexity of its molecule.

CHAPTER III

PHYSIOLOGICAL IDEA OF LIFE

ACCEPTING the complicated processes of metabolism and reproduction as distinguishing characteristics of life, the force back of these distinctive powers or properties of living matter becomes a fruitful topic for investigation. Thompson in the 'Science of Life' discusses this question. "Over and over again in the history of Biology the doctrine of a special vital force has arisen, held sway for a time, and then disappeared. It arises as a reaction from the false simplicity of premature solutions, or as a despairing retreat in the face of baffling problems, or as the result of misunderstanding the real aim of science.

"The doctrine is an old one, for even if we ignore the speculations of the ancients, it must date at least from Paracelsus and Van Helmont. As it has naturally taken very different forms in different generations, the word 'vitalism,' so often used, has little definite meaning. There is a sense in which no modern physiologist is a vitalist, since none rejects physico-chemical interpretations as the early French vitalists did; there is a sense in which all modern physiologists are vitalists, since none pretends to know the secret of that particular synthesis which even the simplest of organisms illustrates.

"The phrase 'vital force' may be used as a general expression for the energies resident in living matter, and may serve to suggest that we do not at present understand them, or how they are related in the unity of the organism.

But the phrase was originally used to denote a 'hyper-mechanical force,' a mystical power, resident in living creatures, and quite different from thermic, electric, and other forms of energy. This was the meaning attached to the phrase by the disciples of Haller, by Louis Dumas (1765-1813), by Reil (1759-1813), and the other early vitalists. It can only be said that an appeal to such a force violates the scientific method, and abandons the scientific problem. Again and again, in regard to particular points, subsequent progress has shown that the loss of faith in science was premature.

"According to the hypothesis of vitalism the phenomena of life are inexplicable apart from a special vital force exclusively resident in organisms, and different from the chemico-physical energies of the inanimate world. Thus the great pathologist and anatomist Henle (d. 1885) believed in a non-material agent associated with the organism, 'presiding over the metabolism of the body, capable of reproducing the typical form, and of endless partition without diminution of intensity.' It is altogether an error to suppose that a refusal to believe in such a special 'vital force' implies materialism. The questions are quite separate; the former has to do with scientific method, the latter is a philosophical theory. Thus Huxley was certainly no believer in 'a vital force,' yet he was clearly an idealist; and the same might be said of many.

"Every physiologist will, I believe, admit that he cannot at present give a physico-chemical interpretation of contractility or of irritability, of digestion or of absorption, of respiration or of circulation. What he can give is a partial analysis of these functions in simpler terms. This must remain the case until we discover the secret of the synthesis which the simplest unicellular organism expresses. The 'neo-vitalists,' such as Bunge and Rindfleisch, emphasize the fact that there is no present possibility of giving a complete chemico-physical restatement of any observed function; that there are always residual phenomena; and

that the known physico-chemical causes do not seem adequate to the result. In other words, the categories of mechanism, of chemistry and physics, cannot be forced upon vitality without doing violence to the very idea of the organism—a complex adaptive synthesis of matter and energy whose secret remains unread. When the neo-vitalists go further, and insist on an idealistic as opposed to a materialistic conception, they may be quite correct, but they are raising another question, which is philosophical rather than biological."

Huxley, in his famous address 'On the Physical Basis of Life,' has well stated the case against the existence of a vital force. "What justification is there, then," he says, "for the assumption of the existence in the living matter of a something which has no representative, or correlative, in the not living matter which gave rise to it? What better philosophical status has 'vitality' than 'aquosity'? And why should 'vitality' hope for a better fate than the other 'itys' which have disappeared since Martinus Scriblerus accounted for the operation of the meat-jack by its inherent 'meat-roasting quality,' and scorned the 'materialism' of those who explained the turning of the spit by a certain mechanism worked by the draft of the chimney?

"If scientific language is to possess a definite and constant signification whenever it is employed, it seems to me that we are logically bound to apply to the protoplasm, or physical basis of life, the same conceptions as those which are held to be legitimate elsewhere. If the phenomena exhibited by water are its properties, so are those presented by protoplasm, living or dead, its properties. If the properties of water may be properly said to result from the nature and disposition of its component molecules, I can find no intelligible ground for refusing to say that the properties of protoplasm result from the nature and disposition of its molecules."

This idea of the physical basis of life, so clearly stated by Huxley, has been further developed by Dr. Michael

Foster, whose line of thought is as follows: "The more the molecular problems of physiology are studied, the stronger becomes the conviction that the consideration of what we call structure and composition must, in harmony with the modern teachings of physics, be approached under the dominant conception of modes of motion. The physicists have been led to consider the qualities of things as expressions of internal movements; even more imperative does it seem to us that the biologist should regard the qualities of living matter (including structure and composition) as in like manner the expressions of internal movements. He may speak of living matter as a complex substance, but he must strive to realize that what he means by that is a complex whirl, an intricate dance, of which what he calls chemical composition, histological structure and gross configuration are, so to speak, the figures; to him the renewal of protoplasm is but the continuance of the dance, its functions and actions the transferences of the figures. It seems to us necessary, for a satisfactory study of the problems, to keep clearly before the mind the conception that the phenomena in question are the result, not of properties of kinds of matter, but of kinds of motion."

Before passing from the consideration of vital force and the physical basis of life, it will be of interest to compare the views of the biologists Huxley and Foster with that expressed in a lecture by the great physicist, Tyndall.

"The origin, growth and energies of living things," he reminded his hearers, "are subjects which have always engaged the attention of thinking men. To account for them it was usual to assume a special agent, free to a great extent from the limitations observed among the powers of inorganic nature. This agent was called vital force; and, under its influence, plants and animals were supposed to collect their materials and to assume determinate forms. Within the last few years, however, our ideas of vital processes have undergone profound modifications; and the interest, and even disquietude, which the change has excited are

amply evidenced by the discussions and protests which are now common, regarding the phenomena of vitality. In tracing these phenomena through all their moidfications, the most advanced philosophers of the present day declare that they ultimately arrive at a single source of power, from which all vital energy is derived; and the disquieting circumstance is that this source is not the direct fiat of a supernatural agent, but a reservoir of what, if we do not accept the creed of Zoroaster, must be regarded as inorganic force. In short, it is considered as proved that all the energy which we derive from plants and animals is drawn from the sun.

"A few years ago, when the sun was affirmed to be the source of life, nine out of ten of those who are alarmed by the form which this assertion has latterly assumed would have assented, in a general way, to its correctness. Their assent, however, was more poetic than scientific, and they were by no means prepared to see a rigid mechanical signification attached to their words. This, however, is the peculiarity of modern conclusions: that there is no creative energy whatever in the vegetable or animal organism, but that all the power which we obtain from the muscles of man and animals, as much as that which we develop by the combustion of wood or coal, has been produced at the sun's expense.

"To most minds, however, the energy of light and heat presents itself as a thing totally distinct from ordinary mechanical energy. Either of them can nevertheless be derived from the other. Wood can be raised by friction to the temperature of ignition; while by properly striking a piece of iron a skilful blacksmith can cause it to glow. Thus, by the rude agency of his hammer, he generates light and heat. This action, if carried far enough, would produce the light and heat of the sun. In fact, the sun's light and heat have actually been referred to the fall of meteoric matter upon his surface; and whether the sun is thus supported or not, it is perfectly certain that he might be thus

supported. If, then, solar light and heat can be produced by the impact of dead matter, and if from the light and heat thus produced we can derive the energies which we have been accustomed to call vital, it indubitably follows that vital energy may have a proximately mechanical origin.

"In what sense, then, is the sun to be regarded as the origin of the energy derivable from plants and animals? Let us try and give an intelligible answer to this question. Water may be raised from the sea-level to a high elevation, and then permitted to descend. In descending it may be made to assume various forms—to fall in cascades, to spurt in fountains, to boil in eddies, or to flow tranquilly along a uniform bed. It may, moreover, be caused to set complex machinery in motion, to turn millstones, throw shuttles, work saws and hammers, and drive piles. But every form of power here indicated would be derived from the original power expended in raising the water to the height from which it fell. There is no energy generated by the machinery: the work performed by the water in descending is merely the parceling out and distribution of the work expended in raising it.

"In precisely this sense is all the energy of plants and animals the parceling out and distribution of a power originally exerted by the sun. In the case of the water, the source of the power consists in the forcible separation of a quantity of the liquid from a low level of the earth's surface, and its elevation to a higher position, the power thus expended being returned by the water in its descent. In the case of vital phenomena, the source of power consists in the forcible separation of the atoms of compound substances by the sun. We name the force which draws the water earthward 'gravity,' and that which draws atoms together 'chemical affinity'; but these different names must not mislead us regarding the qualitative identity of the two forces. They are both attractions; and, to the intellect, the falling of carbon atoms against oxygen atoms is not more

difficult of conception than the falling of water to the earth.

"The building up of the vegetable, then, is effected by the sun, through the reduction of chemical compounds. The phenomena of animal life are more or less complicated reversals of these processes of reduction. We eat the vegetable, and we breathe the oxygen of the air; and in our bodies the oxygen, which had been lifted from the carbon and hydrogen by the action of the sun, again falls toward them, producing animal heat and developing animal forms. Through the most complicated phenomena of vitality this law runs: the vegetable is produced while a weight rises, the animal is produced while a weight falls.

"But the question is not exhausted here. The water employed in our first illustration generates all the motion displayed in its descent, but the form of the motion depends on the character of the machinery interposed in the path of the water. In a similar way, the primary action of the sun's rays is qualified by the atoms and molecules among which their energy is distributed. Molecular forces determine the form which the solar energy will assume. In the separation of the carbon and oxygen this energy may be so conditioned as to result in one case in the formation of a cabbage, and in another case in the formation of an oak. So also, as regards the reunion of the carbon and the oxygen, the molecular machinery through which the combining energy acts may, in one case, weave the texture of a frog, while in another it may weave the texture of a man.

"The matter of the animal body is that of inorganic nature. There is no substance in the animal tissues which is not primarily derived from the rocks, the water and the air. Are the forces of organic matter, then, different in kind from those of inorganic matter? The philosophy of the present day negatives the question. It is the compounding, in the organic world, of forces belonging equally to the inorganic, that constitutes the mystery and the

miracle of vitality. Every portion of every animal body may be reduced to purely inorganic matter. A perfect reversal of this process of reduction would carry us from the inorganic to the organic; and such a reversal is at least conceivable. The tendency, indeed, of modern science is to break down the wall of partition between organic and inorganic, and to reduce both to the operation of forces which are the same in kind, but which are differently compounded.

"Consider the question of personal identity, in relation to that of molecular form. Thirty-four years ago, Mayer of Heilbronn, with that power of genius which breathes large meanings into scanty facts, pointed out that the blood was 'the oil of the lamp of life,' the combustion of which sustains muscular action. The muscles are the machinery by which the dynamic power of the blood is brought into play. Thus the blood is consumed. But the whole body, tho more slowly than the blood, wastes also, so that after a certain number of years it is entirely renewed. How is the sense of personal identity maintained across this flight of molecules? To man, as we know him, matter is necessary to consciousness; but the matter of any period may be all changed, while consciousness exhibits no solution of continuity. Like changing sentinels, the oxygen, hydrogen and carbon that depart seem to whisper their secret to their comrades that arrive, and thus, while the Non-ego shifts, the Ego remains the same. Constancy of form in the grouping of the molecules, and not constancy of the molecules themselves, is the correlative of this constancy of perception. Life is a wave which in no two consecutive moments of its existence is composed of the same particles.

"Supposing, then, the molecules of the human body, instead of replacing others, and thus renewing a preëxisting form, to be gathered first hand from nature and put together in the same relative positions as those which they occupy in the body. Supposing them to have the

selfsame forces and distribution of forces, the selfsame motions and distribution of motions—would this organized concourse of molecules stand before us as a sentient thinking being? There seems no valid reason to believe that it would not. Or, supposing a planet carved from the sun, set spinning round an axis, and revolving round the sun at a distance from him equal to that of our earth, would one of the consequences of its refrigeration be the development of organic forms? I lean to the affirmative. Structural forces are certainly in the mass, whether or not those forces reach to the extent of forming a plant or an animal. In an amorphous drop of water lie latent all the marvels of crystalline force; and who will set limits to the possible play of molecules in a cooling planet? If these statements startle, it is because matter has been defined and maligned by philosophers and theologians, who were equally unaware that it is, at bottom, essentially mystical and transcendental."

Summarizing the foregoing discussion concerning the nature and general conditions of life and living matter, the fact stands out clearly and distinctly that life from its beginning has been dependent upon the external conditions of the earth's surface. In a mathematical sense, life is a function of the earth's development. Living substance could not exist while the earth was a molten sphere without a solid, cool crust; it was obliged to appear with the same inevitable necessity as a chemical combination, when the necessary conditions were given, and it was obliged to change its form and its composition in the same measure as the external conditions of life changed in the course of the earth's development. It is only a portion of the earth's matter.

The combination of this matter into living substance was as much the necessary product of the earth's development as was the origin of water. It was an inevitable result of the progressive cooling of the masses that formed the earth's crust. Likewise, the chemical, physical and

morphological characteristics of existing living substance are the necessary result of the influence of the external conditions of life upon the internal relations of past living substance. Internal and external vital conditions are inseparably correlated and the expression of this correlation is life.

The artificial production of life would thus seem a theoretical possibility. It has been several times suggested in the discussion of the chemical aspects of life that living matter may sooner or later be produced in the chemists' laboratories. However improbable this suggestion may seem, there are many facts which point to its possibility. Heraclitus compared life with fire. Such a comparison is a pertinent one. Consideration of vital conditions makes this more evident. "It has been shown that life," to quote Verworn, "like fire, is a phenomenon of nature which appears as soon as the complex of its conditions is fulfilled.

"If these conditions are all realized, life must appear with the same necessity as fire appears when its conditions are realized; likewise life must cease as soon as the complex of its conditions has undergone disturbance and with the same necessity with which fire is extinguished when the conditions for its maintenance cease. If, therefore, all vital conditions had been investigated in their minutest details, and it were possible artificially to establish them exactly, life would be produced synthetically, just as fire is produced, and the ideal that existed in the imagination of the medieval alchemists in their attempted production of the homunculus would be achieved."

But, notwithstanding the fact that this theoretical possibility cannot be denied, every attempt at the present time to produce life artificially and to imitate in the laboratory the obscure act of spontaneous generation must appear preposterous. So long as knowledge of the composition of living substance is so imperfect as it is now, the attempt artificially to compound living substance will be like the undertaking of an engineer to put together a machine,

the most important parts of which are wanting. For the present the task of physiology can consist only in the investigation of life. When physiology shall actually have accomplished this, it may think of testing the completeness and correctness of its achievement by the artificial creation of life.

The nature of life has become better understood by the study of death, which to the biologist is simply the cessation of the activities of life. In the first place it is sometimes extremely difficult to distinguish between life and apparent death. Several illustrations will make this clear. In India, where mystery and magic have always prevailed, the belief seems to have existed for a long time that many men, especially the so-called fakirs whose existences are full of privation and self-inflicted torture and who are supposed to possess special holiness, have the remarkable power of voluntarily putting a complete stop to their lives for a time and later resuming them undisturbed and unchanged. A great number of such cases, in which the fakirs have been buried in this condition of suspended animation and after some time have been taken from their graves, have been reported by travelers from India.

It is not to be denied that these tales, especially those of the Indian fakirs, are calculated to awaken distrust, and a sound skepticism is the basis of all good criticism. If, however, from all the known stories their more or less sensational accompaniments be removed, the simple statement remains that certain men can voluntarily put themselves into a state in which no vital phenomena are demonstrable by a more or less superficial examination and can awaken later to normal life. Now sufficient cases are known where physicians by the usual methods of their practice are able to discover absolutely no traces of vital phenomena, where pulse, respiration, movement and irritability are not to be observed; and yet where the person, supposedly dead, has after a time returned to life.

These phenomena are usually termed 'apparent death'

and are connected with those of normal sleep by a series of transition phenomena. Such transition phenomena are the continual sleep in which persons, such as the 'sleeping soldier' and the 'sleeping miner' (authenticated medical cases), continue in a state of depressed vital activity and are absolutely incapable of being awakened, and especially the phenomena of the winter sleep of warm-blooded animals.

However doubtful may be the reported powers of representatives of the vertebrate (or backboned) animals to suspend for a time all vital phenomena, there is no longer any question that many of the lower animals have this power highly developed. As long ago as 1719 Leeuwenhock, the famous improver of the microscope, discovered that small animals, now known as rotifers, may be dried completely to dust and again restored to active life by being placed in water. One of the most remarkable cases of this kind described by Verworn is that of the tardigrade, or bear-animalcule, which, so long as it is in water, performs all its vital phenomena like other animals. "But if it be isolated and allowed to dry slowly upon a slide, it is seen that the more the water evaporates the slower become its movements, until finally they cease entirely when the drop is dried up. Then the body gradually shrinks, the skin become wrinkled and folded, the form becomes gradually indistinguishable, and some time after the animal has become dried it can scarcely be distinguished from a grain of sand. In this dried condition it can remain for many years without undergoing the slightest change. If it be moistened again with water, the return of life to the desiccated body after its sleep can be followed with the microscope. The awakening of the tardigrade or the anabiosis, as Preyer has termed the process, takes place somewhat as follows: The body swells up and becomes extended, the folds and wrinkles slowly disappear, the extremities project and the animal soon assumes its normal shape." At first it remains quiet; then, after a

time, varying, according to the duration of the drying, from a quarter of an hour to several hours, movements, at first slow and feeble, begin and gradually become stronger and more frequent until after some time the animal, unaided, creeps away to resume life at the point where it was interrupted.

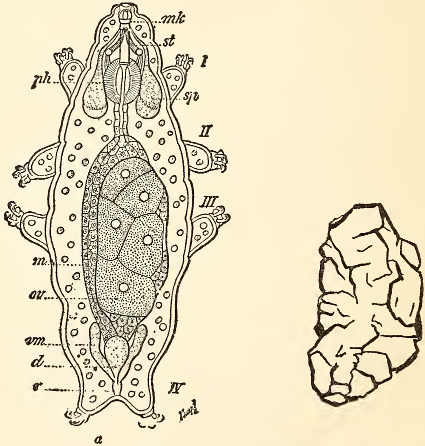


Fig. 1 —A Tardigrade.
a., Creeping in the living state. (Hertwig.) b., Dried, in the state of apparent death. (Verworn.)

Likewise the seeds of many plants retain their power of germination for long periods of time. Here it might be well to add that the well-known story that wheat seeds taken from the graves of Egyptian mummies will germinate, tho thousands of years old, has been disproved by Mariette, the famous Egyptologist. However, from many

observations it seems certain that many plant seeds, when completely dried, can retain their power to germinate for more than a hundred or perhaps two hundred years. These rare facts are of great importance in forming a conception of life and demand exhaustive investigation. The question to be considered is whether it is allowable to regard organisms in this peculiar condition as really lifeless.

It has been pointed out in the earlier part of this chapter that it is metabolism in which the living organism differs from lifeless matter. But this is difficult to settle in some of the concrete cases mentioned above. Do dust-dry animals and seeds possess no metabolism or is this metabolism so depressed or so slight that investigation cannot determine whether the life-process is at a standstill or whether a 'vita minima' exists? Delicate experiments within the last twenty years show no evidence of the use of oxygen or the production of carbonic acid or other products of metabolism in dried organisms sealed for months in airtight tubes.

From the results of these experiments it can no longer be doubted that in desiccated organisms there is a complete standstill of life. Can organisms in this peculiar condition be termed dead? In reality they are lifeless but not dead, for anabiosis is possible after the application of water, while nothing can bring dead organisms back to life. The distinction between the dried and the dead organism lies in the fact that in the former all the internal vital conditions are still fulfilled and only the external conditions in part have appeared, while in the latter the internal vital conditions have experienced irreparable disturbances, altho the external conditions can still be fulfilled.

Preyer illustrates this distinction very happily. He compares the dried organism to a clock that has been wound but has stopped, so that it needs only a push to set it going, and the dead organism to a clock that is broken and cannot be made to go by a push. Hence a sharp distinction must be made between dried and dead organisms. But dried or-

ganisms cannot be called living, for they exhibit no vital phenomena, and, as has been seen, vital phenomena are the criterion of life. It is best, therefore, to apply to them the expression 'apparently dead.'

Still more difficult than cases of apparent death is the determination of an exact limit between life and active death. In daily life it is easy to distinguish the dead organism from the living, for from the human body and from the higher animals a general conception of death has been formed and it is usual to consider it as occurring at the moment when the heart, hitherto never quiet, stands still and the individual ceases to breathe. But this is merely following the superficial habits of daily life and taking into consideration only the gross differences that make their appearance at that time, without noticing the continuance of certain phenomena after this all-important moment.

The criterion of life is formed only by the vital phenomena—*i.e.,* by the various phases in which the vital process, or the metabolism, becomes evident to the senses. But if this criterion be applied to the human being at the moment usually termed the moment of death, it is found that in reality he is not dead.

It is true that the spontaneous gross muscular movements cease, the man becomes relaxed and quiet. But the muscles frequently remain for several hours sensitive to external influences, responding to the latter with twitchings and movements of the limbs, in other words, showing vital phenomena. A moment even comes when the muscles gradually contract once more spontaneously, this is the death-stiffening (rigor mortis). Not until this has passed is the life of the muscles extinguished. Nevertheless, even then the body is not entirely dead. Certain parts only, certain organs or cell-complexes, such as the cells of the nervous system and of the muscles, no longer show vital phenomena; but other cells and cell-complexes continue to live unchanged long after rigor mortis has passed.

What moment then shall be designated as the moment of death? If the existence of vital phenomena be employed as the criterion, then the moment when spontaneous muscular movement, especially the activity of the heart, ceases, cannot consistently be regarded as the moment of death, for other cell-complexes continue to live for a long time thereafter. It is evident, therefore, that there is no definite point of time at which life ceases and death begins; but there is a gradual passage from normal life to complete death which frequently begins to be noticeable during the course of a disease. Death is developed out of life,

It is true that the above example is that of a highly complicated organism. But even in the lowest and simplest microscopic organisms death comes on gradually, and, as in the higher animals, is the end-result of a long series of processes which begin with an irreparable injury to the normal body and lead, step by step, to complete cessation of life activities. To this series of stages in the development of death Schultze and Virchow (1870), famous in pathology, have given the term 'necrobiosis,' the gradual transition between life and death.

It is seen, therefore, that it is impossible to draw a sharp line between life and death, that life and death are only the two end-results of a long series of changes which run their course successively in the organism. "But if, after having established this fact," says Verworn, "the transition stages be left out of consideration for the moment and only the two end-results be considered, on the one side, the uninjured living organism and, on the other, the same organism killed and preserved in alcohol by the modern technical methods, a sharp distinction between these two can be recognised in the fact that in the former the life-process goes on undisturbed, as is evident from the appearance of all vital phenomena, while in the latter it is forever at a complete standstill, as is shown by the absence of even the slightest phenomena of life."

CHAPTER IV

THE ORIGIN OF LIFE

The discussion of the origin of life is introduced by J. Arthur Thomson, of Aberdeen University, in 'The Science of Life' with the following words: "If it were the object of this book to give a statement of the established facts of biology, our discussion of the origin of life might be condensed into a single sentence: We do not know anything in regard to the origin of life. The only certainty is a negative one—there is no established case in which living organisms have arisen apart from parent organisms of the same kind."

There are two distinct questions connected with the origin of life: First, how did it first originate in the early eras of the world's history? and, second, does life to-day originate spontaneously in inorganic matter? It seems best to consider these separately. Professor Max Verworn, of the University of Jena, gives a good summary of the various theories concerning the origin of life, and it is from his 'General Physiology' that some of the following illustrations have been taken.

The origin of life upon the earth is a first and leading problem. The idea that the earth was once in a highly heated condition is accepted in modern science. And this fact that it once was in a condition in which the temperature was enormously high and not a drop of water existed upon it, in short, a condition in which the vital conditions that are now regarded as indispensable to the existence of

organisms were wanting, will always be an important factor with which all speculations upon the origin of life upon the earth must deal. Obviously in that highly heated condition life in its present form, at least, could not have existed. Then one of two things must have happened after the earth cooled down—either inorganic matter must have become living matter or living matter must have come from other planets than this.

But if life came hither from other worlds, the interesting question as to the beginning of life remains. Helmholtz has said, "Organic life either has begun to exist at some one time or has existed for eternity." Evidently the two notions are mutually exclusive. Which affords the most reasonable basis of explanation? The idea that life has existed in the universe from eternity and has simply been transferred from one world to another is known as the theory of 'cosmozoa.' It was suggested by H. E. Richter (1865, '70 and '71), who assumed that among particles moving about in space, like meteorites, there are the germs of microscopic organisms capable of establishing life on the earth. Helmholtz and Sir William Thomson have discussed this question of the transference of living matter from other heavenly bodies to this earth and both term this view not unscientific. Helmholtz (1884) held that meteors which swarm everywhere in space might be the bearers of such germs in their cool interior cavities. He thought it a correct scientific procedure to question whether life may not be even as old as matter and its germs passed from world to world and developed wherever favorable conditions exist.

In the present condition of knowledge it is scarcely possible to obtain a direct contradiction of this doctrine and conclusive proof of its impossibility. This will be true so long as experience does not suffice to enable man to recognise as wholly impossible the transfer of protoplasmic germs of life from one world to another. But, altho direct contradiction of the doctrine is at present impossible, the

thought that living substance has existed from eternity and has never originated from inorganic substance appears in the highest degree improbable.

Setting aside the 'cosmozoa' theory as improbable, and before considering the alternative view of the spontaneous generation of life from lifeless matter on the earth, mention should be made of Preyer's view that living matter is the primary thing and that lifeless matter has been derived from the living. According to this view, life must have existed when the earth was incandescent. Preyer fits his theory to this fact by giving to his conception of life a scope wider than that usually allowed, including not only present living matter but also incandescent liquid masses as they once existed. Life then had no origin; it existed even in the beginning of the material universe. In fact, the view seems to identify life with motion. Evidently the language used constitutes the chief difference between this and the doctrine that living matter as now recognised was spontaneously generated from matter customarily termed lifeless. Whether from primeval conditions incandescent matter, which from our usual standpoint would certainly be considered lifeless, was really living and separated out that which we call lifeless or whether it was lifeless with the power to evolve into living matter are questions of greater metaphysical flavor than of direct interest in the biological science of to-day. In either case the original incandescent matter must have possessed the potentiality of evolving and differentiating into what is now recognised as living and lifeless matter. It matters little whether in philosophical moods it is sought to establish the primary vital force, for after all, as has been shown, vital force is not unique among the forces of the universe.

One of the most suggestive works discussing the origin of life from lifeless matter on the earth is by the famous German physiologist Pflüger (1875). He discussed the problem from the standpoint of physiological chemistry

and follows it out far into detail. The essential point of Pflüger's investigation is constituted by the chemical characteristics of proteid as that substance with which life in its essentials is inseparably united. There exists a fundamental difference between dead proteid, as it occurs—*e.g.*, in egg-albumen, and living proteid, as it constitutes living substance; this difference is the self-decomposition of the latter. All living substance is continually being decomposed, in some degree spontaneously and more through outside influences, while dead proteid under favorable conditions remains intact for an unlimited time.

Further, Pflüger assumes on scientific grounds that the presence of cyanogen in living matter is responsible for the characteristic properties of living proteid, especially its great powers of decomposition. From this he concludes that the beginning of organic life was in cyanogen. Hence the problem of the origin of living substance culminates in the question: How does cyanogen arise? Here, organic chemistry presents the highly significant fact, that cyanogen and its compounds, such as potassium cyanide, ammonium cyanide, hydrocyanic acid, cyanic acid, etc., arise only in an incandescent heat—*e.g.*, when the necessary nitrogenous compounds are brought in contact with burning coal, or when the mass is heated to a white heat. "Accordingly, nothing is clearer than the possibility of the formation of cyanogen-compounds when the earth was wholly or partially in a fiery or heated state." Moreover, chemistry shows how the other essential constituents of proteid, such as the hydrocarbons, the alcohol radicals, etc., can likewise arise synthetically in heat.

"It is seen," says Pflüger, "how strongly and remarkably all facts of chemistry point to fire as the force that has produced by synthesis the constituents of proteid. In other words, life is derived from fire, and its fundamental conditions were laid down at a time when the earth was still an incandescent ball. If now we consider the im-

measurably long time during which the cooling of the earth's surface dragged itself slowly along, cyanogen and the compounds that contain cyanogen and hydrocarbon substances had time and opportunity to indulge extensively their great tendency toward transformation and polymerization and to pass over with the aid of oxygen, and later of water and salts, into that self-destructive proteid, living matter."

Pflüger thereupon summarizes his ideas in the following sentences: "Accordingly, I would say that the first proteid to arise was living matter, endowed in all its radicals with the property of vigorously attracting similar constituents, adding them chemically to its molecule, and thus growing ad infinitum. According to this idea, living proteid does not need to have a constant molecular weight; it is a huge molecule undergoing constant, never-ending formation and constant decomposition, and probably behaves toward the usual chemical molecules as the sun behaves toward small meteors.

"In the plant, living proteid simply continues to do what it has always done since its origin—*i.e.*, regenerate or grow; wherefore I believe that all proteid existing in the world to-day was derived directly from the first proteid."

This idea of Pflüger's in essentials is generally accepted, for most present-day biologists prefer to think of life as having originated directly from substances usually regarded as lifeless and of all existing living proteid as having descended in direct continuity from the first proteid. Moreover, some biologists follow Helmholtz and others in thinking that the first proteid may possibly have originated in some other part of the universe, but astronomy and geology offer good reason for believing that living matter might have originated on the earth when in its evolution to its present state conditions became right for its development.

However, notwithstanding all the speculations concerning the subject, it must be recognised that the problem is

one of metaphysics rather than of natural science. The ordinary methods of scientific investigation are not applicable to the problem and one can only theorize as to the basis of life as it is known. But there cannot be any certainty that life in its beginning, under possibly vastly different conditions from those obtaining to-day, possessed the distinctive properties discovered in it by modern science.

That master of modern philosophical biology, Thomas H. Huxley, discussed the origin of life in his Presidential Address before the British Association for the Advancement of Science, forty years ago, and his words, while expressing the ideas outlined above, stand high among the statements of the philosophical problems of biology. "Looking back through the prodigious vista of the past," he writes, "I find no record of commencement of life, and therefore I am devoid of any means of forming a definite conclusion as to the condition of its appearance. Belief, in the scientific sense of the word, is a serious matter and needs strong foundations. To say, therefore, in the admitted absence of evidence, that I have any belief as to the mode in which the existing forms of life have originated, would be using words in a wrong sense.

"But expectation is permissible where belief is not; and if it were given to me to look beyond the abyss of geologically recorded time to the still more remote period when the earth was passing through physical and chemical conditions which it can no more see again than a man can recall his infancy, I should expect to be a witness of the evolution of living substance from non-living matter. I should expect to see it appear under forms of great simplicity, endowed, like existing fungi, with the power of determining the formation of new living matter from such matters as ammonium carbonates, oxalates and tartrates, alkaline and earthy phosphates, and water, without the aid of light. That is the expectation to which analogical reasoning leads me; but I beg you once more to recollect

that I have no right to call my opinion anything but an act of philosophical faith."

The second question to be considered is that of spontaneous generation. The view that life originally began in non-living matter—*i.e.*, was spontaneously generated, is commonly accepted by twentieth-century biology. But it should be noted that "belief in the spontaneous generation of simple living matter in the early ages of the world's history is quite different from the belief that even to-day new living matter originates spontaneously without the influence of preëxisting living matter."

This idea that living things, including even animals as complicated as flies and frogs, originate directly from lifeless matter, long after the first origin of life, has been widely accepted and is believed even to-day by many unscientific people. It is to this supposed origin of living matter within the period of human history that the term 'spontaneous generation' ('archegony,' 'abiogenesis,' 'generatio spontanea' or 'aequivoca') is most commonly applied and few authors of articles on the subject have included discussion of the first origin of life. Obviously the fundamental problems would be the same, no matter whether the spontaneous appearance of life in lifeless matter occurred in the beginning of all life or occurs to-day. But the first is entirely beyond the power of scientific investigation, while if life now originates spontaneously a critical application of the methods of modern science ought to prove it and to throw light on the method of origin. Investigators have therefore been stimulated to test the truth of the theory and to look for the key which will unlock the mystery of the first origin of life.

A vast amount of critical work has been done with the result that the biologists of the Victorian era proved that life does not originate spontaneously in any of the cases claimed to have been observed. In other words, life does not now spontaneously originate in lifeless matter so far as is known. This does not mean that it cannot or does

not originate in some unknown form. This is a possibility which biologists recognise, and so they stand in an open-minded attitude ready to witness the origin of life from lifeless matter and really somewhat disappointed in that this opportunity has not yet come.

The story of the theory of spontaneous generation is one of the most fantastic in all biology. Thomson says: "If the longevity of a belief were an index to its truth, the theory of spontaneous generation should rank high among the veracities, for it flourished throughout twenty centuries and more. We cannot trace the history of the theory in all its details, but the story may be recommended to the psychological historian as a labyrinth of error, with glimpses of truth at every turn."

The belief in spontaneous generation is recorded in literature back as far as Anaximander (611-547 B.C.). He believed that eels and other aquatic forms are produced directly from lifeless matter. His pupil Anaximenes (588-524 B.C.) "introduced the idea of primordial terrestrial slime, a mixture of earth and water, from which, under the influence of the sun's heat, plants, animals and human beings are directly produced—in the abiogenetic fashion," says Osborn in 'From the Greeks to Darwin.' Diogenes and Xenophanes, the first to recognise the true nature of fossils, also believed in spontaneous generation. Then came the "father of natural history," Aristotle (384-322 B.C.), who fostered this idea so strongly that it has persisted for more than twenty centuries. He taught that not only small animals, but even frogs, snakes and eels are produced spontaneously from mud.

Long after Aristotle, men found no difficulty in believing in cases of spontaneous generation which would now be rejected as monstrous by the most fanatical supporter of the doctrine. Shell-fish of all kinds were considered to be without parental origin. Eels were supposed to spring spontaneously from the fat ooze of the Nile. Caterpillars were the spontaneous products of the leaves on which they

fed; while winged insects, serpents, rats and mice were all thought capable of being generated without sexual intervention.

The development of embryology and the knowledge of the life-histories of plants and animals gradually set aside many supposed cases of spontaneous generation. A little observation showed that individuals of these species developed from eggs produced by parents of the same species. But it is interesting to note that certain philosophers, notably among them being Augustine (353-430), still held to spontaneous generation as occasionally happening in animals reproducing by the sexual method. According to Augustine, from the beginning there had existed two kinds of germs of living things: first, visible ones, placed by the Creator in animals and plants; and second, invisible ones, latent and becoming active only under certain conditions of combination and temperature. It is these which produce plants and animals in great numbers without any coöperation of existing organisms. This was a naturalistic way of explaining the sudden appearance of countless numbers of frogs, insects and other animals which to-day offers no difficulty, now that the remarkable fertility of animals is known.

Even a man like Cesalpino (1519-1603), who did some excellent botanical work, and had, long before Harvey, some clear ideas as to the circulation of the blood, "believed that frogs might be generated from the mud with the help of sunshine," says Thompson, "and even suggested a similar origin of the aboriginal Americans. The botanists were no better than the zoölogists. One of their favorite notions was that the green dust which grows in damp weather on trees and stones, which is now known to consist of unicellular Algae, such as 'Pleurococcus,' was a standing evidence of the genetic connection between the dead and the living, between the mineral and the vegetable; even Bacon of Verulam believed in the spontaneous origin of some higher plants, like thistles, from earth; and

the Italian botanist Matthioli regarded the duckweed, whose leaf-like shoots are so common on the surface of pools, as a condensation of the still water, and a starting-point for higher forms of plant life; while even Harvey continued to believe in spontaneous generation."

A scientific experiment to test spontaneous generation was first undertaken by Francesco Redi, a distinguished Italian physician and scholar. The origin of maggots from putrefying flesh had long been accepted as a clear case of spontaneous generation. Tyndall, in an article on spontaneous generation, writes of this as follows: "Lacking the checks imposed by fuller investigation, the conclusion that flesh possesses and exerts this generative power is a natural one. I well remember when a child of ten or twelve seeing a joint of imperfectly salted beef cut into, and coils of maggots laid bare within the mass. Without a moment's hesitation I jumped to the conclusion that these maggots had been spontaneously generated in the meat. I had no knowledge which could qualify or oppose this conclusion, and for the time it was irresistible. The childhood of the individual typifies that of the race, and the belief here enunciated was that of the world for nearly two thousand years."

To the examination of this very point the celebrated Francesco Redi addressed himself in 1668. He had seen the maggots of putrefying flesh, and reflected on their possible origin. But he was not content with mere reflection, nor with the theoretic guesswork which his predecessors had founded upon their imperfect observations. Watching meat during its passage from freshness to decay, prior to the appearance of maggots he invariably observed flies buzzing round the meat and frequently alighting on it. The maggots, he thought, might be the half-developed progeny of these flies.

"The inductive guess precedes experiment, by which, however, it must be finally tested. Redi knew this, and acted accordingly. Placing fresh meat in a jar and cover-

ing the mouth with paper, he found that, tho the meat putrefied in the ordinary way, it never bred maggots, while the same meat placed in open jars soon swarmed with these organisms. For the paper cover he then substituted fine gauze, through which the odor of the meat could rise. Over it the flies buzzed, and on it they laid their eggs, but the meshes being too small to permit the eggs to fall through, no maggots were generated in the meat. They were, on the contrary, hatched upon the gauze. By a series of such experiments Redi destroyed the belief in the spontaneous generation of maggots in meat, and with it doubtless many related beliefs. The combat was continued by Vallisneri, Schwammerdam and Réaumur, who succeeded in banishing the notion of spontaneous generation from the scientific minds of their day. Indeed, as regards such complex organisms as those which formed the subject of their researches, the notion was banished forever, so far as accepted science was concerned." However, to this day many untutored persons firmly believe that dead horse-hairs placed in water transform themselves into horse-hair eels and that meat generates maggots and other forms of life.

In the latter half of the seventeenth century the great improvement of the microscope as an instrument of investigation paved the way to a new phase of the discussion of spontaneous generation. This came about because of the fact that the instrument brought into view a world of life formed of individuals so minute—so close as it seemed to the ultimate particles of matter—as to suggest an easy passage from atoms to organisms. Animal and vegetable infusions exposed to the air were found clouded and crowded with creatures far beyond the reach of unaided vision, but perfectly visible to an eye strengthened by the microscope. With reference to their origin these organisms were called 'Infusoria.' Stagnant pools were found full of them, and the obvious difficulty of assigning a germinal origin to existences so minute furnished the

precise condition necessary to give new play to the notion of heterogenesis or spontancous generation.

Many scientific men of that day took up the question of the origin of the microscopic organisms. A Scotch priest, Turbervill Needham (1750), showed that animalcules (Infusorians and the like) appeared even in decoctions which had been boiled and corked up. As we should now say, this result was due to imperfect sterilization and imperfect corking of the tubes; but it was used by Buffon, who was much interested in Needham's work, to bolster up a pet theory of his, that life resided in indestructible organic molecules, and that these were liberated after death or in decomposition as the aforesaid Infusorians or animalcules.

This result of Needham's was contradicted in 1777 by the Abbé Spallanzani who charged his flasks with organic infusions, sealed their necks with the blowpipe, subjected them in this condition to the heat of boiling water, and subsequently exposed them to temperatures favorable to the development of life. The infusions continued unchanged for months, and when the flasks were subsequently opened no trace of life was found. Spallanzani's flasks must have contained but little air and it was objected by the chemists, who had now discovered oxygen, that life could not be expected where this gas was more or less absent, and that the boiling process might irretrievably injure the 'organic molecules.'

Schultze and Schwann (1836, 1837) were thus led to make fresh experiments; they carefully boiled the infusions and supplied air which had been passed through red-hot tubes or acids—, no animacules appeared; they then supplied air which had not been so purified, and in the same infusions the animalcules appeared. Schwann's final conclusion was "that putrefaction is due to decompositions of organic matter attendant on the multiplication therein of minute organisms. These organisms are derived not from the air but from something contained in the air, which is destroyed by a sufficiently high temperature."

The next step in advance came in 1854, when Schroeder and Dusch did what is now so often done as a class experiment: they boiled infusions, and while the steam was coming off plugged the neck of the flask with cotton-wool. This allows the passage of oxygen, but keeps back germs; and in most cases the sterilization is quite effective. In 1859 a book was published which seemed to overturn some of the best established facts of previous investigators. Its title was 'Héterogénie,' and its author was F. A. Pouchet, Director of the Museum of Natural History at Rouen, a strong believer in the theory of spontaneous generation. "Never," says Tyndall, "did a subject require the exercise of the cold critical faculty more than this one. To a man of Pouchet's temperament the subject was full of danger—danger not lessened by the theoretic bias with which he approached it."

Pasteur's work in chemistry and in special research in fermentation had prepared him for this investigation. He knew more than Pouchet as to the insidious ways of microbes; he showed the weak point of his antagonist's experiments, and gained the prize offered in 1860 by the Academy, for "well-contrived experiments to throw new light upon the question of spontaneous generation." Pasteur threw light on the subject by his study of the organized particles—many of them living or dead bacteria—which float in the air. He opened twenty sealed flasks containing organic infusions in the pure air of the Mer de Glace, and only one thereafter showed signs of life; but eight out of twenty opened on the plains, and all of the twenty opened in town, developed germs. These and other experiments, carried out with a severity perfectly obvious to the instructed scientific reader, and accompanied by a logic equally severe, restored the conviction that, even in these lower reaches of the scale of being, life does not appear without the operation of antecedent life. Pasteur's brusque conclusion was that "spontaneous generation is a chimera."

These experiments by Pasteur laid the foundation for a long series of studies of micro-organisms by himself, Tyndall and others. Tyndall describes the famous experiment in which he proves that "not in the air, nor in the infusions, nor in anything continuous diffused through the air, but in discrete (organic) particles, suspended in the air and nourished by the infusions, we are to seek the cause of life" as follows: "Supposing an infusion intrinsically barren, but readily susceptible of putrefaction when exposed to common air, to be brought into contact with unilluminable air (air freed from dust particles), what would be the result? It would never putrefy. Let a condensed beam be sent through a large flask or bolthead containing common air. The track of the beam is seen within the flask—the dust revealing the light, and the light revealing the dust. Cork the flask, stuff its neck with cotton-wool, or simply turn its mouth downward and leave it undisturbed for a day or two. Examined afterward with the luminous beam, no track is visible; the light passes through the flask as through a vacuum. The floating matter has abolished itself, being now attached to the interior surface of the flask. Were it the object effectually to detain the dirt, that surface might be coated with some sticky substance. Here, then, without 'torturing' the air in any way, is a means of ridding it, or rather of enabling it to rid itself, of floating matter.

"We have now to devise a means," he continues, "of testing the action of such spontaneously purified air upon putrescible infusions. Wooden chambers, or cases, accordingly are constructed, having glass fronts, side-windows and back-doors. Through the bottoms of the chambers test-tubes pass air-tight; their open ends, for about one-fifth of the length of the tubes, being within the chambers. Provision is made for a free connection through sinuous channels between the inner and the outer air. Through such channels, tho open, no dust will reach the chamber. The top of each chamber is perforated by a circular hole

two inches in diameter, closed air-tight by a sheet of india-rubber. This is pierced in the middle by a pin, and through the pinhole is pushed the shank of a long pipette, ending above in a small funnel. The shank also passes through a stuffing-box of cotton-wool moistened with glycerine; so that, tightly clasped by the rubber and wool, the pipette is not likely in its motions up and down to carry any dust into the chamber.

"The chamber is carefully closed and permitted to remain quiet for two or three days. Examined at the beginning by a beam sent through its windows, the air is found laden with floating matter, which in three days has wholly disappeared. To prevent its ever rising again, the internal surface of the chamber was at the outset coated with glycerine. The fresh but putrescible liquid is introduced into the six tubes in succession by means of the pipette. Permitted to remain without further precaution, every one of the tubes would putrefy and fill itself with life. The liquid has been in contact with the dust-laden air outside by which it has been infected, and the infection must be destroyed. This is done by plunging the six tubes into a bath of heated oil and boiling the infusion. The time requisite to destroy the infection depends wholly upon its nature. Two minutes' boiling suffices to destroy some contagia, whereas two hundred minutes' boiling fails to destroy others. After the infusion has been sterilized, the oil-bath is withdrawn, and the liquid, whose putrescibility has been in no way affected by the boiling, is abandoned to the air of the chamber.

"With such chambers I tested, in the autumn and winter of 1875-6, infusions of the most various kinds, embracing natural animal liquids, the flesh and viscera of domestic animals, game, fish and vegetables. More than fifty chambers, each with its series of infusions, were tested, many of them repeatedly. There was no shade of uncertainty in any of the results. In every instance we had, within the chamber, perfect limpidity and sweetness, which in some cases lasted for more than a year—without the

chamber, with the same infusion, putridity and its characteristic smells. In no instance was the least countenance lent to the notion that an infusion deprived by heat of its inherent life, and placed in contact with air cleansed of its visibly suspended matter, has any power to generate life anew.

"The argument is now to be clenched by an experiment which will remove every residue of doubt as to the ability of the infusions here employed to sustain life. We open the back doors of our sealed chambers, and permit the common air with its floating particles to have access to our tubes. For three months they have remained pellucid and sweet—flesh, fish and vegetable extracts purer than ever cook manufactured. Three days' exposure to the dusty air suffices to render them muddy, fetid and swarming with infusorial life. The liquids are thus proved, one and all, ready for putrefaction when the contaminating agent is applied."

Many such experiments as these established beyond a doubt the fact that no known case of spontaneous generation occurs under the present conditions of life. 'Omne vivum e vivo' would correctly express the accepted view of the twentieth-century biologists, provided it be translated 'all life from life' under known existing conditions, but probably life from the lifeless in its first origin on this earth or elsewhere.

That all living matter existing to-day has descended directly from preëxisting living matter is the doctrine of 'Biogenesis,' the rival of the dethroned doctrine of 'Abiogenesis.' Observe that the doctrine of biogenesis refers simply to what is now happening and has been happening in all times of which we have strictly scientific records. The theory of biogenesis thus understood as the prevailing natural process will still stand even if, as seems probable, some lucky physiological chemist succeeds in synthesizing under artificial conditions new living matter, entirely independent of preëxisting living matter. He will have done

nothing more than repeat under unusual and artificially controlled conditions the processes which probably occurred when in the evolution of matter in the post-incandescent ages of the earth living proteid, progenitor of all future organisms, first came into existence. So far as the future succession of organisms on this earth is concerned, it cannot even be imagined that living matter synthesized in scientific laboratories will play any part. The law of biogenesis, now established as firmly as that of gravitation, may be expected to stand as the very rock of ages in the science of biology.

Such is in outline the story of one of the greatest fallacies with which modern science has had to deal. But, strange to say, the establishment of the truth of biogenesis, which directly is of little importance to man, has laid the foundation for practical researches of a most momentous kind. To Pasteur and the other great generals in the last battles against the theory of spontaneous generation is due the honor of the establishment of the new science of bacteriology which in the last two decades has come to play such a mighty part in the development of modern life.

CHAPTER V

CELL LIFE

In the two preceding chapters living substance has been spoken of as existing in separate organic individuals, plants and animals. It is not known to exist in a mass not organized as an individual plant or animal. Many early philosophers did conceive of living matter as existing without individualization. Thus Oken (1805), in his Ur-Schleim theory, when he says that every organic thing came from primitive slime which originated in the sea from organic matter in the course of planetary evolution, simply repeated an idea passed down by the Greek philosopher Anaximenes and others.

Haeckel's theory of the Monera as the simplest of living things allies him to this belief. He says: "In the Monera, the simplest conceivable organisms, the whole body consists merely of plasm, corresponding to the 'primitive slime' of the earlier natural philosophers." And again, in 'The Natural History of Creation,' he describes the Monera as "simple, soft, albuminous lumps . . . without component parts, whose whole albuminous body is as homogeneous in itself as an inorganic crystal."

Huxley also for a time supported this view. In 1869 he described a peculiar sticky mud from the bottom of the Atlantic. The stickiness was apparently due to the presence of innumerable lumps of a transparent gelatinous substance without discoverable nuclei or membranous envelopes. Huxley interpreted this matter to be masses

of protoplasm. He thought it a new form of the simple animate things (Monera) which had been described by Haeckel, and therefore named it Bathybius Haeckelii. Haeckel himself examined the mud and agreed with Huxley's interpretation. Later studies, however, con-

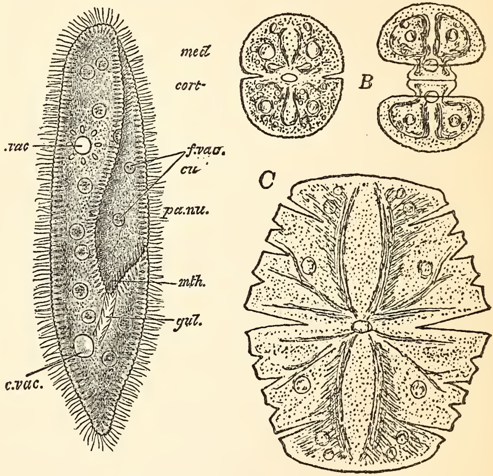


Fig. 2 —Unicellular Animals and Plants.
A., animal, 'Paramœcium caudatum'; c. vac., contractile vacuole; gul., gullet; mth., mouth; f. vac., food vacuole; B. and C., plants, 'Micrasterias' and 'Cosmarium.'

vinced Huxley that the slime was in reality some sort of inorganic precipitate, and at the British Association meeting in 1879 he made a public renunciation of Bathybius.

Leaving this interesting historical conception of living matter in extensive undifferentiated masses, the idea of

the individualization of living substance prevails in modern biological science. An organic individual is a unitary mass of living substance. Microscopic study of plants and animals shows them to be made up of these unitary masses—the cells. An illustration will make this point clear. Dissection shows that an organ of an animal's body is composed of several building materials, or tissues, such as muscular tissue, nervous tissue, bony tissue, etc. The microscopic study of these tissues reveals the fact that they are composed of small masses of protoplasm—the cells. Hence a plant or animal with several tissues is a multicellular organism. There are many simple plants and animals whose body consists of a single cell and these are called unicellular animals. Every such simple organism is an individual. The cell then is the lowest stage of individuality.

It is true, as will be explained in detail later, that the microscope reveals different structures in cells. Especially characteristic are the main body of the cell, the 'cytoplasm,' and the 'nucleus' imbedded in it. This suggests the possibility that the cell is composed of still lower individuals. However, many studies have shown that neither nucleus nor cytoplasm can exist independently, and hence they cannot be regarded as unit masses or individuals. The cell is the lowest stage of individuality known to modern biology.

Looking at the organic world synthetically, the cell stands prominent in a scheme of the five stages of individuality found there.

Individuals of the first order are cells. They represent elementary organisms that are not composed of lower units capable of life. An example is any unicellular animal or plant.

Individuals of the second order are tissues. The tissues are associations of individuals of the first order, each one of which is like the others. Examples are the muscular

and nervous tissues of an animal, the conducting and supporting tissues of a plant.

Individuals of the third order are organs. The organs are associations of various kinds of individuals of the second order. Examples are the stomach and heart of an animal, the leaf and root of a plant.

Individuals of the fourth order are complex organisms. These are associations of various individuals of the third order. Examples are common animals and plants, whose bodies consist of organs united.

Individuals of the fifth order are communities. The communities are associations of individuals of the fourth order.

It should be noted that an individual of a higher order consists of an assemblage of those of the next lower order. Thus communities consist of persons, persons of organs,

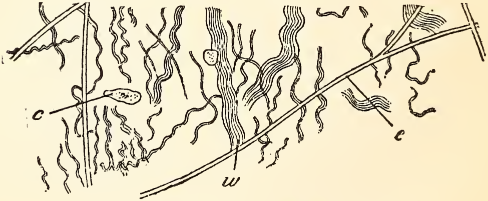


Fig. 3 —Connective Tissues—Animal.
c., cells; e., elastic fibers; w., white fibers all embedded in a delicate ground substance. (Parker and Parker.)

organs of tissues, and tissues of cells. In the end all living individual plants and animals are composed of cells and the cell is the seat of those events the expression of which is life. The cell is the life unit, the elementary organism, or as Virchow has said, the vital elementary unit.

The realization that it is in the cell that the answers

to the great problems of biology are to be found is quite modern. Nevertheless this fact has already profoundly modified many phases of the science of life. Professor Wilson of Columbia University, justly regarded as one of the foremost biologists who have worked at the problems of cytology, or the biology of cells, has well outlined the influence of the cell theory on modern biology. He says: "It was the cell-theory that first brought the structure of plants and animals under one point of view, by revealing their common plan of organization. It was through the cell-theory that Kölliker, Remak, Nägeli and Hoffmeister opened the way to an understanding of the nature of embryological development, and the law of

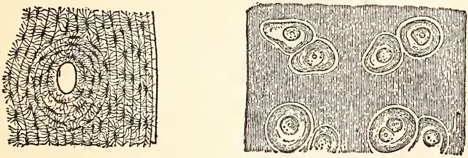


Fig. 4 —Bony and Cartilaginous Tissue.

genetic continuity lying at the basis of inheritance. It was the cell-theory again which, in the hands of Goodsir, Virchow and Max Schultze, inaugurated a new era in the history of physiology and pathology, by showing that all the various functions of the body, in health and in disease, are but the outward expression of cell-activities. And at a still later day it was through the cell-theory that Hertwig, Fol, Van Beneden and Strasburger solved the long-standing riddle of the fertilization of the egg and the mechanism of hereditary transmission. No other biological generalization, save only the theory of organic evolution, has brought so many apparently diverse phenomena under a common point of view or has accomplished more for the unification of knowledge. The cell-theory must, therefore,

be placed beside the evolution-theory as one of the foundation stones of modern biology."

The history of the development of the idea that cells are the elementary units of living matter is essential to an understanding of present-day problems, and therefore a rapid survey of the important historical points may be made. These have been well traced by Oscar Hertwig, Professor at Berlin, in his famous 'Die Zelle und die Gewebe.' "The conception or idea connected with the word 'cell,' used scientifically," he says, "has been considerably altered during the last fifty years. The history of the various changes in this conception, or the history of the cell-theory, is of great interest, and nothing could be more suitable than to give a short account of this history in order to introduce the beginner to the series of conceptions connected with the word 'cells'; this, indeed, may prove useful in other directions. For while, on the one hand, we see how the conception of the cell which is at present accepted, has developed gradually out of older and less complete conceptions, we realize, on the other hand, that we cannot regard it as final or perfect; but on the contrary, we have every ground to hope that better and more delicate methods of investigation, due partly to improved optical instruments, may greatly add to our present knowledge, and may perhaps enrich it with a quite new series of conceptions.

"The theory that organisms are composed of cells was first suggested by the study of plant-structure. At the end of the seventeenth century the Italian, Marcellus Malpighi, and the Englishman, Grew, gained the first insight into the more delicate structure of plants; by means of low magnifying powers they discovered, in the first place, small room-like spaces, provided with firm walls, and filled with fluid, the cells; and in the second, various kinds of long tubes, which, in most parts, are embedded in the ground tissue, and which, from their appearance, are now called spiral ducts or vessels. Much greater impor-

tance, however, was attached to these facts after the investigations which were carried on in a more philosophical spirit by Bahn toward the end of the eighteenth century were published.

"Caspar Friedrich Wolff, Oken, and others, raised the question of the development of plants, and endeavored to show that the ducts and vessels originated in cells. Above all, Treviranus rendered important service by proving in his treatise, entitled 'Vom inwendigen Bau der Gewächse,' published in 1808, that vessels develop from cells.

"The study of the lowest plants has also proved of the greatest importance in establishing the cell-theory. Small algae were observed, which during their whole lifetime remain either single cells, or consist of simple rows of cells, easily to be separated from one another. Finally, the study of the metabolism of plants led investigators to believe that, in the economy of the plant, it is the cell which absorbs the nutrient substances, elaborates them, and gives them up in an altered form. Thus, at the beginning of the last century, the cell was recognised by many investigators as the morphological and physiological elementary unit of the plant."

These views, however, only obtained general acceptance after the year 1838, when M. Schleiden, who is so frequently cited as the founder of the cell-theory, published in Müller's 'Archives' his famous paper, 'Beiträge zur Phytogenesis.' In this paper Schleiden endeavored to explain the mystery of cell-formation. He thought he had found the key to the difficulty in the discovery of the English botanist, R. Brown, who, in the year 1833, while making investigations upon orchids, discovered nuclei. Schleiden made further discoveries in this direction; he showed that nuclei are present in many plants, and as they are invariably found in young cells, the idea occurred to him that the nucleus must have a near connection with the mysterious beginning of the cell, and in consequence must be of great importance in its life-history.

The way in which Schleiden made use of this idea, which was based upon erroneous observations, to build up a theory of phytogenesis, must now be regarded as a mistake; on the other hand, it must not be forgotten that his perception of the general importance of the nucleus was correct up to a certain point, and that this one idea has in itself exerted an influence far beyond the narrow limits of the science of botany, for it is owing to this that the cell-theory was first applied to animal tissues. For it is just in animal cells that the nuclei stand out most distinctly from among all the other cell-contents, thus showing most evidently the similarity between the histological elements of plants and animals. Thus this little treatise of Schleiden's in 1838 marks an important historical turning-point, and since this time the most important work in the building up of the cell-theory has been done upon animal tissues.

Attempts to represent the animal body as consisting of a large number of extremely minute elements had been made before Schleiden's time, as is shown by the hypotheses of Oken, Heusinger, Raspail, and many other writers. However, it was impossible to develop these theories further, since they were based upon so many incorrect observations and false deductions that the good in them was outweighed by their errors.

Schwann, however, was the first to attempt to frame a really comprehensive cell-theory which should refer to all kinds of animal tissues. During the year 1838 Schwann, in the course of a conversation with Schleiden, was informed of the new theory of cell-formation, and of the importance which was attached to the nucleus in plant-cells. It immediately struck him, as he himself relates, that there are a great many points of resemblance between animal and vegetable cells. He therefore, with most praiseworthy energy, set on foot a comprehensive series of experiments, the results of which he published in 1839.

Thus Schwann originated a theory which, altho imper-

fect in many respects, yet is applicable both to plants and animals, and which, further, is easily understood, and in the main correct. According to this theory, every part of the animal body is either built up of elements, correspond-

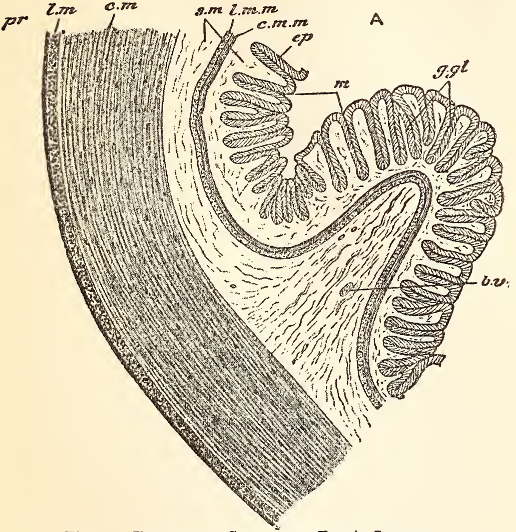


Fig. 5 —Transverse Section of Frog's Stomach.

Showing the muscular, connective and epithelial tissues of which it is composed. l. m., longitudinal muscles; b. v., blood vessel; c. m., circular muscles; s. m., connective tissue; ep., epithelical tissue; g. gl., gastric gland. (Parker and Parker.)

ing to the plant-cells, massed together, or is derived from such elements which have undergone certain metamorphoses. This theory has formed a satisfactory foun-

dation upon which many further investigations have been based.

However, as has been mentioned already, the conception which Schleiden and Schwann formed of the plant and animal element was incorrect in many respects. They both defined the cell as a small vesicle, with a firm membrane enclosing fluid contents, that is to say as a small chamber, or 'cellula,' in the true sense of the word. They considered the membrane to be the most important and essential part of the vesicle, for they thought that in consequence of its chemico-physical properties it regulated the metabolism of the cell.

The series of conceptions which now associate with the word 'cell' are, thanks to the great progress made during the last fifty years, essentially different from the above. Schleiden and Schwann's cell-theory has undergone a radical reform, having been superseded by the Protoplasmic theory, which is especially associated with the name of Max Schultze.

The History of the Protoplasmic theory is also of supreme interest. Even Schleiden observed in the plant-cell, in addition to the cell sap, a delicate transparent substance containing small granules; this substance he called plant slime. In the year 1846 Mohl called it Protoplasm, a name which has since become so significant, and which before had been used by Purkinje for the substance of which the youngest animal embryos are formed. Further, he presented a new picture of the living appearance of plant protoplasm; he discovered that it completely filled up the interior of young plant cells, and that in larger and older cells, it absorbed fluid, which collected into droplets or vacuoles. Finally, Mohl established the fact that protoplasm, as has been already stated by Schleiden about the plant slime, shows strikingly peculiar movements; these were first discovered in the year 1772 by Bonaventura Corti, and later in 1807 by C. L. Tre-

viranus, and were described as "the circulatory movements of the cell-sap."

By degrees further discoveries were made, which added to the importance attached to these protoplasmic contents of the cell. In the lowest algae, as was observed by Cohn and others, the protoplasm draws itself away from the cell membrane at the time of reproduction, and forms a naked oval body, the swarm-spore, which lies freely in the cell cavity; this swarm-spore soon breaks down the membrane at one spot, after which it creeps out through the opening, and swims about in the water by means of its cilia, like an independent organism; but it has no cell membrane.

Similar facts were discovered through the study of the animal cell, which could not be reconciled with the old conception of the cell. A few years after the enunciation of Schwann's theory, various investigators, Kölliker, Bischoff and others, observed many animal cells in which no distinct membrane could be discovered, and in consequence a lengthy dispute arose as to whether these bodies were really without membranes, and hence not cells, or whether they were true cells. Further, movements similar to those seen in plant protoplasm were discovered in the granular ground substance of certain animal cells, such as the lymph corpuscles. In consequence Remak applied the term protoplasm, which Mohl had already made use of for plant cells, to the ground substance of animal cells.

Important insight into the nature of protoplasm was afforded by the study of the lowest organism, Rhizopoda (Amoebae), Myxomycetes, etc. Dujardin had called the slimy, granular, contractile substance of which they are composed 'Sarcode.' Subsequently, Max Schultze and de Bary proved, after most careful investigation, that the protoplasm of plants and animals and the sarcode of the lowest organisms are identical.

In consequence of these discoveries, investigators, such as Nägeli, Alexander Braun, Leydig, Kölliker, Cohn, de Bary, etc., considered the cell membrane to be of but minor

importance in comparison to its contents; however, the credit is due to Max Schultze, above all others, of having made use of these later discoveries in subjecting the cell theory of Schleiden and Schwann to a searching critical examination, and of founding a protoplasmic theory. He attacked the former articles of belief, which it was necessary to renounce, in four excellent tho short papers, the first of which was published in the year 1860.

He based his theory that the cell-membrane is not an essential part of the elementary organisms of plants and animals on the following three facts: First, that a certain substance, the protoplasm of plants and animals, and the sarcode of the simplest forms, which may be recognised by its peculiar phenomena of movement, is found in all organisms; secondly, that altho as a rule the protoplasm of plants is surrounded by a special firm membrane, yet under certain conditions it is able to become divested of this membrane, and to swim about in water as in the case of naked swarm-spores; and finally, that animal cells and the lowest unicellular organisms very frequently possess no cell-membrane, but appear as naked protoplasm and naked sarcode. It is true that he retains the term 'cell,' which was introduced into anatomical language by Schleiden and Schwann; but he defines it as a small mass of protoplasm endowed with the attributes of life.

Hence it is evident that the term 'cell' is incorrect. That it, nevertheless, has been retained, may be partly ascribed to a kind of loyalty to the vigorous combatants, who, as Brücke expresses it, conquered the whole field of histology under the banner of the cell-theory, and partly to the circumstance, that the discoveries which brought about the new reform were only made by degrees, and were only generally accepted at a time when, in consequence of its having been used for several decades of years, the word cell had taken firm root in the literature of the subject.

Since the time of Brücke and Max Schultze knowledge

of the true nature of the cell has increased considerably. Great insight has been gained into the structure and the vital properties of the protoplasm, and in especial, knowledge of the nucleus, and of the part it plays in cell-multiplication, and in sexual reproduction, has recently made great advances. The earlier definition, "the cell is a little mass of protoplasm," must now be replaced by the follow-

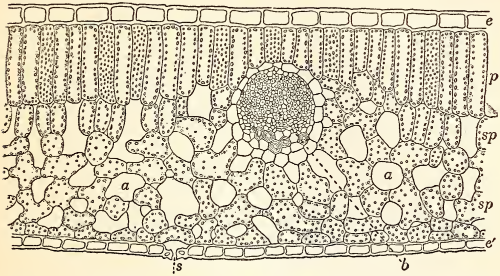


Fig. 6 —Cross-section of a Leaf Showing Tissues and the Cells of Which They Are Composed.

e., epidermal tissue showing epidermal cells; p., palisade parenchyma; sp., spongy parenchyma cells; b., vein composed of conducting and supporting tissue; a., air spaces; s., stoma. (Bergen and Davis.)

ing: "The cell is a little mass of protoplasm, which contains in its interior a specially formed portion, the nucleus."

It is evident from the preceding history of the cell-theory that the term 'cell' is a biological misnomer; for cells only rarely assume the form implied by the word of hollow chambers surrounded by solid walls. The term is merely a historical survival of a word casually employed by the botanists of the seventeenth century to designate the cells of certain plant-tissues which, when viewed in

section, give somewhat the appearance of a honeycomb. The cells of these tissues are, in fact, separated by conspicuous solid walls which were mistaken by Schleiden, followed by Schwann, for their essential part. The living substance contained within the walls was at first overlooked or was regarded as a waste-product, a view based upon the fact that in many important plant-tissues such as cork or wood it may wholly disappear, leaving only the lifeless walls. Researches showed, however, that most

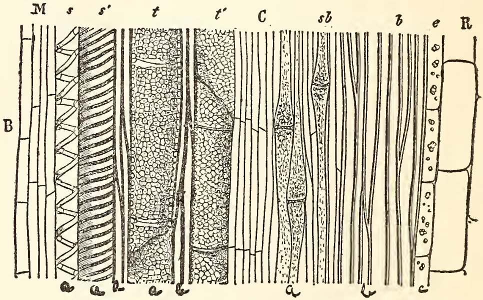


Fig. 7 —Section Through a Part of a Sunflower Stem Showing Tissues and the Cells of Which They Are Composed. a., conducting tissue; b., supporting tissue; c., parenchyma. (Vines.)

living cells are not hollow but solid bodies, and that in many cases—for example, the colorless corpuscles of blood and lymph—they are naked masses of protoplasm not surrounded by definite walls. Thus it was proved that neither the vesicular form nor the presence of surrounding walls is an essential character, and that the cell-contents—*i.e.*, the protoplasm—must be the seat of vital activity.

Within the cell contents lies a body, usually of definite rounded form, known as the nucleus, and this in turn

often contains one or more smaller bodies or nucleoli. By some of the earlier workers the nucleus was supposed to be, like the cell-wall, of secondary importance, and many forms of cells were described as being devoid of a nucleus ('cytodes' of Haeckel). Nearly all later researches have indicated, however, that the characteristic nuclear material, whether forming a single body or scattered in smaller masses, is always present, and that it plays an essential part in the life of the cell. Besides the presence of protoplasm and nucleus, no other structural features of the cell are yet known to be of universal occurrence.

"We may," says Wilson, "therefore still accept as valid the definition given more than thirty years ago by Leydig and Max Schultze, that a cell is a mass of protoplasm containing a nucleus, to which we may add Schultze's statement that both nucleus and protoplasm arise through the division of the corresponding elements of a preëxisting cell."

The form of cells is highly variable. In isolated cells, especially those floating freely in a fluid and not subjected to unequal pressure, the spherical form is common, but even such free cells may be modified in form by internal movements and differentiations of the cell-substance. For example, some egg-cells are spherical while others are ovoidal; muscle cells are elongated; nerve cells much branched; the white cells of the blood are irregular in shape because of their movements. But no matter how diverse the form of the cells, their structure is essentially the same.

As already suggested, a cell-wall or membrane is usually, tho not always present. Sometimes the cell-substance has no more of a limiting membrane than has a drop of oil floating in water, that is, there is simply an undifferentiated film separating it from its surroundings. The cell-mass or cell-substance consists of protoplasm, the active living substance, in which may be embedded granules of lifeless substances. If the term protoplasm is accepted as syn-

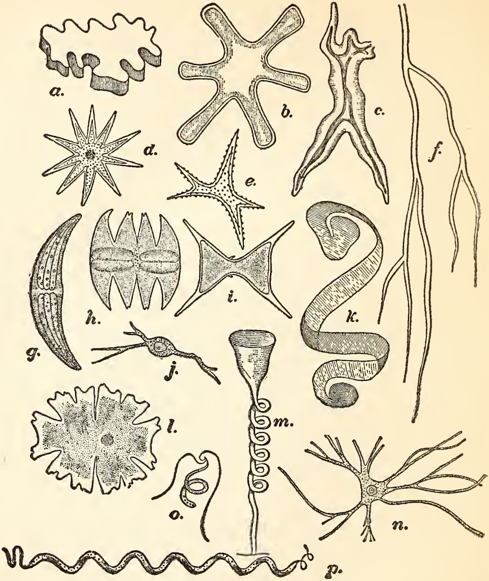


Fig. 8 —Examples of Cell-shapes.

a., epidermal cell of 'Callitriche'; b., stellate cell of flowering rush; c., bast cell of larch; d., stellate hair of 'Deutzia'; e., stellate cell of yellow water-lily; f., part of a branching lactiferous cell of 'Euphorbia'; g., h., i., p., one-celled plants; j., a human cartilage cell; k., outer cell-wall of a pollen grain of 'Thunbergia'; m., diagram of a one-celled animal; n., nerve-cell; o., germ-cell of a stonewort, unequally magnified. (Sedgwick and Wilson.)

onymous with living matter, then there is protoplasm both in the main body of the cell and also in the specially differentiated mass, most commonly central in position, known as the nucleus. It is convenient to call the protoplasm outside the nucleus 'cytoplasm' and that within the nucleus the 'karyoplasm' or 'nucleoplasm.'

In the cytoplasm there are various lifeless substances (metaplasm). Some of these, like fat and starch, are reserve food absorbed but not yet used by the cell, others, like pigment and the cell-wall, are the lifeless products of life activity. The amount of metaplasm is frequently vastly greater than the amount of protoplasm in a cell. For example, a hen's egg just before leaving the ovary is a cell about one inch in diameter (the yolk of the egg). A small white disk on the upper surface consists of concentrated protoplasm, but the greater part of this enormous egg-cell is made up of stored yolk (metaplasm) to be used as food by the chick in its development during incubation.

The nucleus is usually surrounded by a definite membrane, the nuclear membrane. Within this membrane and embedded in the general protoplasmic basis, there are granules or masses of a substance which has a strong affinity for certain chemical dyes, hence called 'chromatin.' When this chromatin is massed into rod-shaped bodies, as happens in the process of cell-division, the term 'chromosomes' is applied to these masses of chromatin. Then, too, other bodies, nucleoli, are often present. Their nature is not clearly understood, probably because they are extremely variable.

Careful study of the nucleus during all its phases gives reason to believe that its structural basis is similar to that of the cell-body; and that during the course of cell-division, when the nuclear membrane usually disappears, cytoplasm and karyoplasm come into direct continuity. For these and other reasons the terms 'nucleus' and 'cell-body' should probably be regarded as only topographical

expressions denoting two differentiated areas in a common structural basis. The terms 'karyoplasm' and 'cytoplasm' possess, however, a specific significance owing to the fact that there is on the whole a definite chemical contrast between the nuclear substance and that of the cell-body, the former being characterized by the abundance of a substance rich in phosphorus known as 'nuclein,' while the latter contains no true nuclein and is especially rich in albuminous substances such as nucleoalbumins, albumins, globulins, and the like, which contain little or no phosphorus.

"Both morphologically and physiologically," says Wilson, "the differentiation of the active cell-substance into nucleus and cell-body must be regarded as a fundamental character of the cell because of its universal, or all but universal, occurrence, and because there is reason to believe that it is in some manner an expression of the dual aspect of the fundamental process of metabolism, constructive and destructive, that lies at the basis of cell life."

In addition to the cytoplasm or cell-body and the nucleus recent biologists believe that an extremely minute body lying just outside the nuclear membrane, and known as the 'centrosome,' is an essential element of the cell. The centrosome has been seen in a large number of cells, is known to play an important part in cell-division and in the fertilization of egg-cells and has been regarded by some cytologists as the 'dynamic center' of the cell. It is still under investigation, and the interested reader should refer to such technical books as Wilson's 'The Cell in Development and Inheritance' for the latest studies of its structure. Some animal and plant-cells appear to differ so much from one another as to their form and contents, that, at first sight, they seem to have nothing in common, and hence it seems impossible to compare them. For instance, if a cell at the growing-point of a plant be taken and compared with one filled with starch granules from the tuber of a potato, or if the contents of an embryo cell from a

germinal disk be compared with those of a fat cell, or of one from the egg of an Amphibian filled with yolk granules, the inexperienced observer sees nothing but contrasts. Nevertheless, all these exceedingly different cells are seen on closer examination to be similar in one respect —*i.e.,* in the possession of a very important, peculiar mixture of substances, which is sometimes present in large quantities, and sometimes only in traces, but which is never wholly absent in any elementary organism. In this mixture of substances the wonderful vital phenomena may very frequently be observed (contractility, irritability, etc.); and, moreover, since in young cells, in lower organisms, and in the cells of growing-points and germinal areas, it is in the cell-substance alone (the nucleus of course being excepted) that these properties have been observed, this substance has been recognised as the chief supporter of the vital functions. It is the protoplasm or 'forming matter.'

In order to know what protoplasm is, it is advisable to examine it in those cells in which it is present in large quantities, and in which it is as free as possible from admixture with other bodies; and among such the most suitable are those organisms from the study of which the founders of the protoplasmic theory formed their conception of the nature of this substance. Such organisms are young plant-cells, Amoebae, and the lymph corpuscles of vertebrates.

The protoplasm of unicellular organisms, and of plant and animal cells appears as a viscid substance, which is almost always colorless, which will not mix with water, and which, in consequence of a certain resemblance to slimy substances, was called by Schleiden the 'slime of the cell.' Its refractive power is greater than that of water, so that the most delicate threads of protoplasm, altho colorless, may be distinguished in this medium. Minute granules, the 'microsomes,' which look only like dots, are always present in greater or less numbers in all protoplasm,

and may be seen with a low power of the microscope to be embedded in a homogeneous ground substance.

As to the very minute structure of protoplasm, "most of the earlier observers," says Wilson, "regarded the meshwork as a fibrillar structure, either forming a continuous network or reticulum somewhat like the fibrous network of a sponge or consisting of disconnected threads, whether simple or branching ("filar theory" of Flemming), and the same view is widely held at the present time. The meshwork has received various names in accordance with this conception, among which may be mentioned 'reticulum,' 'threadwork,' 'spongioplasm,' 'mitome,' 'filar substance,' all of which are still in use. Under this view the 'granules' described by Schultz, Virchow and still earlier observers have been variously regarded as nodes of the network, optical sections of the threads, or as actual granules ("microsomes") suspended in the network as described above."

Widely opposed to these views is the 'alveolar theory' of Bütschli, which has won an increasing number of adherents. Bütschli regards protoplasm as having a foam-like alveolar structure ("Wabenstruktur"), nearly similar to that of an emulsion and he has shown in a series of beautiful experiments that artificial emulsions variously prepared, may show the microscope a marvelously close resemblance to living protoplasm, and further that drops of oil-emulsion suspended in water may even exhibit amoeboid changes of form.

The two (three) general views hereinbefore outlined may justly be designated respectively as the fibrillar (reticular or filar) and alveolar theories of protoplasmic structure, and each of them has been believed by some of its adherents to be universally applicable to all forms of protoplasm. Beside them may be placed, as a third general view, the granular theory especially associated with the name of Altmann, by whom it has been most fully developed, tho a number of earlier writers have

held similar views. According to Altmann's view, which apart from its theoretical development approaches in some respects that of Bütschli, protoplasm is compounded of innumerable minute granules which alone form its essential active basis; and while fibrillar or alveolar structures may occur, these are of only secondary importance.

Which of these views is correct? The present tendency of cytologists is toward the conclusion that none of them is of universal application and that all exist under certain conditions. In support of this may be cited the studies of Professor Wilson, who has been led to the conclusion that "no universal formula for protoplasmic structure can be given. In that classical object, the echinoderm-egg, for example, it is easy to satisfy oneself, both in the living cell and in sections, that the protoplasm has a beautiful alveolar structure, exactly as described by Bütschli in the same object. This structure is here, however, entirely of secondary origin; for its genesis can be traced step by step during the growth of the ovarian eggs through the deposit of minute drops in a homogeneous basis, which ultimately gives rise to the interalveolar walls. In these same eggs the astral systems formed during their subsequent division are, I believe, no less certainly fibrillar; and thus we see the protoplasm of the same cell passing successively through homogeneous, alveolar, and fibrillar phases, at different periods of growth and in different conditions of physiological activity.

"There is good reason to regard this as typical of protoplasm in general. Bütschli's conclusions, based on researches so thoro, prolonged and ingenious, are entitled to great weight; yet it is impossible to resist the evidence that fibrillar and granular as well as alveolar structures are of wide occurrence; and while each may be characteristic of certain kinds of cells, or of certain physiological conditions, none is common to all forms of protoplasm. If this position be well grounded, we must admit that the attempt to find in visible protoplasmic structure any ade-

quate insight into its fundamental modes of physiological activity has thus far proved fruitless. We must rather seek the source of these activities in the ultramicroscopical organization, accepting the probability that apparently homogeneous protoplasm is a complex mixture of substances which may assume various forms of visible structure according to its modes of activity.

"Much discussion has been given to the question as to which of the visible elements of the protoplasm should be regarded as the 'living' substance proper. Later discussions have shown the futility of this discussion, which is indeed largely a verbal one, turning as it does on the sense of the word 'living.' In practice we continually use the word 'living' to denote various degrees of vital activity. Protoplasm deprived of nuclear matter has lost, wholly or in part, one of the most characteristic vital properties, namely, the power of synthetic metabolism; yet we still speak of it as 'living,' since it still retains for a longer or shorter period such properties as irritability and the power of coordinated movement; and, in like manner, various special elements of protoplasm may be termed 'living' in a still more restricted sense.

"In its fullest meaning, however, the word 'living' implies the existance of a group of cooperating activities more complex than those manifested by any one substance or structural element. I am, therefore, entirely in accord with the view urged by Sachs, Kölliker, Verworn, and other recent writers, that life can only be properly regarded as a property of the cell-system as a whole; and the separate elements of the system would, with Sachs, better be designated as 'active' or 'passive,' rather than as 'living' or 'lifeless.' Thus regarded, the distinction between 'protoplasmic' and 'metaplasmic' substances, while a real and necessary one, becomes after all one of degree."

CHAPTER VI

CELL DIVISION

AMONG the vital phenomena exhibited by cells and visible through the microscope, none is so strikingly distinctive of living matter as is the process of cell-division. Closely connected with it are some of the greatest problems of biology. By the continued division of an original germ-cell or egg-cell all the tissue cells of a multicellular animal arise and the germ-cell itself arises in the parent body from other cells by cell-division. Thus the problem is one of the central facts of development and inheritance.

The rapid advance of biological research is continually adding weight to the conclusions reached years ago that every cell originates by division of some preexisting cell (Omnis cellula e cellula). This is now regarded as one of the fundamental laws of biology and obviously is a corollary of the biogenetic law spoken of which states that all living matter (known to exist only in cells) originates from preexisting living matter.

"How do cells originate?" was the problem which troubled the biologists of the early part of the nineteenth century. Schleiden and Schwann tried to answer the question, but their answer was entirely wrong. They held that cells, which they were fond of comparing to crystals, formed themselves like crystals in a mother-liquor. Schwann even went further, teaching that young cells developed, not only within the mother-cell (as propounded by Schleiden), but also outside of it, in an organic sub-

stance, which is frequently present in animal tissues as intercellular substance, and which he called also 'Cytoblastem.' Thus Schwann taught that cells were formed spontaneously both inside and outside of the mother-cell, which would be a genuine case of spontaneous generation from formless germ substance."

These were indeed grave fundamental errors, from which, however, the botanists were the first to extricate themselves. In the year 1846 a general law was formulated in consequence of the observations of Mohl, Unger, and above all, Nägeli. This law states that new plant cells only spring from those already present, and further that this occurs in such a manner, that the mother-cell becomes broken up by dividing into two or more daughter-cells. This was first observed by Mohl.

It was much more difficult to disprove the theory, that the cells of animal tissues arise from cytoblasts, and this was especially the case in the domain of pathological anatomy, for it was thought that the formation of tumors and pus could be traced back to cytoblasts. At last, after many mistakes, more light was thrown upon the subject of the genesis of cells in the animal kingdom also, until finally the cytoblastic theory was absolutely disproved by Virchow, who originated the formula, "Omnis cellula e cellula." No spontaneous generation of cells occurs either in plants or animals. The many millions of cells of which, for instance, the body of a vertebrate animal is composed, have been produced by the repeated division of one cell, the ovum, in which the life of every animal commences.

The older histologists were unable to discover what part the nucleus played in cell-division. For many decades two opposing theories were held, of which now one and now the other obtained temporarily the greater number of supporters. According to the one theory, which was held by most botanists, the nucleus at each division was supposed to break up and become diffused throughout the

protoplasm, in order to be formed anew in each daughter-cell. According to the other, the nucleus was supposed to take an active part in the process of cell-division, and, at the commencement of it, to become elongated and constricted at a point, corresponding with the plane of division which is seen later, and to divide into halves, which separate from one another and move apart.

Later discoveries (1873-1880) revealed the extremely interesting formations and metamorphoses, which are seen in the nucleus during cell-division. These investigations have all pointed to the same conclusion, that the nucleus is a permanent and most important organ of the cell, and that it evidently plays a distinct rôle in the cell life during division. Just as the cell is never spontaneously generated, but is produced directly by the division of another cell, so the nucleus is never freshly created, but is derived from the constituent particles of another nucleus. The formula 'omnis cellula e cellula' might be extended by adding 'omnis nuclei e nucleo.'

Since about 1876 it has been recognised that there are two widely different types of cell-division. In one type there appears to be a simple constriction of the nucleus and cell-body. This is known as 'direct,' 'akinetic' or 'amitotic' division. The second type is vastly more complicated, as will be described. To this are now applied the terms 'direct division,' 'karyokinesis' or 'mitosis.' The terms mitosis and amitosis (referring to the presence or absence of chromosomes in the dividing cells) are preferred by most biologists.

As to the occurrence of these two types, modern research has demonstrated the fact that amitosis or direct division, regarded by Remak and his immediate followers as of universal occurrence, is in reality a rare and exceptional process; and there is reason to believe, furthermore, that it is especially characteristic of highly specialized cells incapable of long-continued multiplication or such as are in the early stages of degeneration, for instance, in glandu-

lar epithelia and in the cells of transitory embryonic envelopes, where it is of frequent occurrence. Whether this view be well founded or not, it is certain that in all the higher and in many of the lower forms of life, indirect division or mitosis is the typical mode of cell-division. It is by mitotic division that the germ-cells arise and are prepared for their union during the process of maturation, and by the same process the oösperm segments and gives rise to the tissue-cells. It occurs not only in the highest forms of plants and animals, but also in such simple forms as the rhizopods, flagellates and diatoms. It may, therefore, be justly regarded as the most general expression of the 'eternal law of continuous development' on which Virchow insisted.

The phenomena which occur during the process of mitosis are very varied and very complicated; nevertheless they conform to certain laws which are wonderfully constant in both plants and animals. The main feature of the process consists in this, that the various substances which are present in the resting nucleus, undergo a definite change of position, and the nuclear membrane being dissolved, enter into closer union with the cytoplasmic substance.

During this process the whole mass of chromatin in the nucleus becomes transformed into fine thread-like segments, the chromosomes, the number of which remains constant for each species of plant or animal. These chromosomes are arranged in a characteristic manner on a spindle-like structure of achromatic material extending between the two centrosomes. Each chromosome then divides longitudinally into two daughter chromosomes which for a time lie parallel with each other and are closely connected. Next, these daughter chromosomes separate into two groups, dividing themselves equally between the two groups to form the foundation of the daughter nuclei. The cell itself meanwhile becomes divided in such

a way that each of the two cells formed by the division possesses one of the daughter nuclei.

The manner in which these changes are brought about is so interesting that it seems wise to give a more detailed outline of the process. Professor Wilson, in "The Cell in Development and Inheritance" gives a description in essentials as follows:

"In the present state of knowledge it is somewhat difficult to give a connected general account of mitosis, owing to the uncertainty that hangs over the nature and functions of the centrosome. For the purpose of the following preliminary outline, we shall take as a type mitosis in which a distinct and persistent centrosome is present, as has been mostly clearly determined in the maturation and cleavage of various animal eggs, and in the division of the testis-cells.

"In such cases the process involves three parallel series of change, which affect the nucleus, the centrosome and the cytoplasm of the cell-body respectively. For descriptive purposes it may conveniently be divided into a series of successive stages or phases, which, however, graduate into one another and are separated by no well-defined limits. These are: (1) The 'Prophases,' or preparatory changes; (2) the 'Metaphase,' which involves the most essential step in the division of the nucleus; (3) the 'Anaphases,' in which the nuclear material is distributed; (4) the 'Telophases,' in which the entire cell divides and the daughter-cells are formed.

"1. Prophases.—As the cell prepares for division, the most conspicuous fact is a transformation of the nuclear substance, involving both physical and chemical changes. The chromatin-substance rapidly increases in staining-power, loses its net-like arrangement and finally gives rise to a definite number of separate intensely staining bodies, usually rod-shaped, known as chromosomes. As a rule this process takes place as follows: The chromatin resolves itself little by little into a more or less convoluted

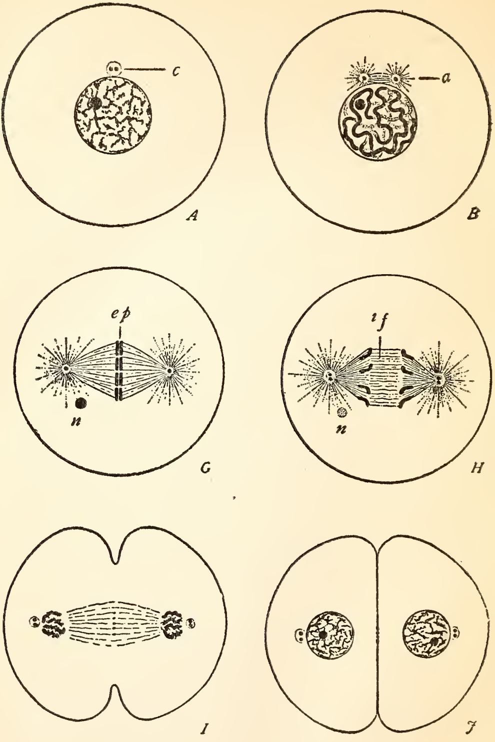


Fig. 9 —Diagrams Illustrating Mitosis.
A., the resting cell; B., early prophase; G., metaphase; H., anaphase; I., telophase; J., division complete. (Wilson.)

thread, known as the skein or spireme, and its substance stains far more intensely than that of the reticulum. The spireme-thread is at first fine and closely convoluted, forming the 'close spireme.' Later the thread thickens and shortens and the convolution becomes more open.

"In some cases there is but a single continuous thread, in others the thread is from its first appearance divided into a number of separate pieces or segments, forming a segmented spireme. In either case it ultimately breaks transversely to form the chromosomes, which in most cases have the form of rods, straight or curved, tho they are sometimes spherical or ovoidal and in certain cases may be joined together in the form of rings. The staining-power of the chromatin is now at a maximum. As a rule the nuclear membrane meanwhile fades away and finally disappears, tho there are some cases in which it persists more or less completely through all the phases of division. The chromosomes now lie naked in the cell and the ground-substance of the nucleus becomes continuous with the surrounding cytoplasm.

"The remarkable fact has now been established with high probability that every species of plant or animal has a fixed and characteristic number of chromosomes, which regularly occurs in the division of all of its cells and in all forms arising by sexual reproduction the number is even. Thus in some of the sharks the number is thirty-six; in the mouse, the salamander, the trout, the lily, twenty-four; in the ox, guinea-pig and in man the number is said to be sixteen and the same number is characteristic of the onion. In the grasshopper it is twelve. Under certain conditions the number of chromosomes may be less than the normal in a given species, but these variations are only apparent exceptions.

"The nucleoli differ in their behavior in different cases. True nucleoli or plasmosomes sooner or later disappear, and the greater number of observers agree that they do not take part in the chromosome-formation.

"Meanwhile more or less nearly parallel with these changes in the chromatin a complicated structure known as the amphiaster makes its appearance in the position formerly occupied by the nucleus. This structure consists of a fibrous spindle-shaped body, the spindle, at either pole of which is a star or aster formed of rays or astral fibers radiating into the surrounding cytoplasm, the whole strongly suggesting the arrangement of iron filings in the field of a horseshoe magnet. The center of each aster is occupied by a minute body, known as the centrosome (Boveri, '88), which may be surrounded by a spherical mass known as the centrosphere (Strasburger, '93). As the amphiaster forms the chromosomes group themselves in a plane passing through the equator of the spindle, and thus form what is known as the equatorial plate.

"The entire structure, resulting from the foregoing changes, is known as the karyokinetic or mitotic figure. It may be described as consisting of two distinct parts, namely, the chromatic figure, formed by the deeply staining chromosomes; and the achromatic figure, consisting of the spindle and asters which in general stain but slightly.

"2. Metaphase.—The prophases of mitosis are, on the whole, preparatory in character. The metaphase, which follows, forms the initial phase of actual division. Each chromosome splits lengthwise into two exactly similar halves, which afterward diverge to opposite poles of the splindle, and here each group of daughter-chromosomes finally gives rise to a daughter-nucleus. In some cases the splitting of the chromosomes cannot be seen until they have grouped themselves in the equatorial plane of the spindle, and it is only in this case that the term 'metaphase' can be applied to the mitotic figure as a whole.

"In a large number of cases, however, the splitting may take place at an earlier period in the spireme-stage or even in a few cases in the reticulum of the mother-nucleus. Such variations do not, however, affect the essential fact that the chromatic network is converted into a thread

which, whether continuous or discontinuous, splits throughout its entire length into two exactly equivalent halves. The splitting of the chromosomes, discovered by Flemming in 1880, is the most significant and fundamental operation of cell-division, for by it, as Roux first pointed out ('83), the entire substance of the chromatic network is precisely halved and the daughter-nuclei receive precisely equivalent portions of chromatin from the mother-nucleus. It is very important to observe that the nuclear division always shows this exact quality, whether division of the cell-body be equal or unequal.

"3. Anaphases.—After splitting of the chromosomes, the daughter-chromosomes, arranged in two corresponding groups, diverge to opposite poles of the spindle, where they become closely crowded in a mass near the center of the aster. As they diverge the two groups of daughter-chromosomes are connected by a bundle of achromatic fibers, stretching across the interval between them and known as the interzonal fibers or connecting fibers. In the division of plant cells and often in that of animal cells these fibers show during this period a series of deeply staining thickenings in the equatorial plane forming the cell-plate or mid-body.

"4. Telophases.—In the final phases of mitosis the entire cell is divided in two in a plane passing through the equator of the spindle, each of the daughter-cells receiving a group of chromosomes, half of the spindle and one of the asters with its centrosome. Meanwhile a daughter-nucleus is reconstructed in each cell from the group of chromosomes it contains. When first formed the daughter-nuclei are of equal size. If, however, division of the cell-body has been unequal, the nuclei become, in the end, correspondingly unequal, a fact which, as Conklin and others have pointed out, proves that the size of the nucleus is controlled by that of the cytoplasmic mass in which it lies.

"The fate of the achromatic structures varies considerably and has been accurately determined in only a few

cases. As a rule the spindle fibers disappear more or less completely, but a portion of their substance sometimes persists in a modified form. In dividing plant cells the cell plate finally extends across the entire cell and splits into two layers, between which appears the membrane by which the daughter-cells are cut apart. A nearly similar process occurs in a few animal cells, but as a rule the cell-plate is here greatly reduced and forms no membrane, the cell dividing by constriction through the equatorial plane."

Such is a general description of mitosis. The variations from the type, the origin and fate of the various structures taking part in the division, their relation to each other and the mechanism by means of which the chromosomes divide and separate to form the new nuclei are interesting problems which are to-day being subjected to keen investigation in the laboratories of the cytologists. But most interesting of all perhaps is the problem of the chromosomes in relation to inheritance. This problem will be more fully discussed in the chapter on Heredity.

Some of the most important studies on the physiological relations of nucleus and cytoplasm have been made with one-celled animals. Brandt in 1877 and Nussbaum in 1884 cut certain protozoons into pieces and observed that pieces containing nuclear matter quickly regenerate and produce perfect animals, while the enucleated fragments soon die. One of the most remarkable animals with this power to regenerate is the trumpet animalcule Stentor. Gruber in 1885 found that when this animalcule was fragmented, pieces possessing a large fragment of the nucleus completely regenerated within twenty-four hours. If the nuclear fragment were smaller, the regeneration proceeded more slowly. If no nuclear substance were present, no regeneration took place, tho the wound closed and the fragment lived for a considerable time.

The only exception—but it is a very significant one—was the case of individuals in which the process of normal fission had begun. In these a non-nucleated fragment in

which the formation of a new peristome had already been initiated healed the wound and completed the formation of the peristone. Lillie (1896) has recently found that Stentor may by shaking be broken into fragments of all sizes and that nucleated fragments as small as one-twenty-seventh the volume of the entire animal are still capable of complete regeneration, non-nucleated fragments perish.

Many other such experiments on one-celled animals show that life for a considerable period, perfectly normal movements, susceptibility to stimulus and the power of taking food may continue in enucleated parts of unicellular animals. They lack, however, the power of digestion and secretion and hence cannot continue to live as do the nucleated parts. These facts demonstrate that the nucleus plays an important part in metabolism. Experiments on plants have supported this conclusion. It will be noted that if a unicellular organism be divided into two parts, the part with the nucleus is a complete cell (a mass of protoplasm with a nucleus), while the other part possesses no longer the individuality of a cell and perishes.

It is well known that all animals and plants have a definite limit of growth. From the cytological point of view the limit of body-size appears to be correlated with the total number of cells formed rather than with their individual size. This relation has been carefully studied by Conkline ('96) in the case of the gasteropod Crepidula, an animal which varies greatly in size in the mature condition, the dwarfs having in some cases not more than one-twenty-fifth the volume of the giants. The eggs are, however, of the same size in all and their number is proportional to the size of the adult. The same is true of the tissue-cells. Measurements of cells from the epidermis, the kidney, the liver, the alimentary epithelium and other tissues show that they are on the whole as large in the dwarfs as in the giants. The body-size therefore depends on the total number of cells rather than on their size, individually considered, and the same appears to be the case in plants.

It is in the cells of both plant and animal organisms that the vital functions are carried on. All the vital processes of a complex animal appear to be nothing but the highly developed result of the individual vital processes of

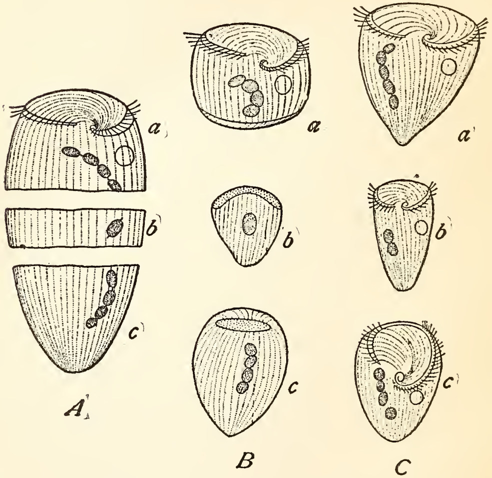


Fig. 10 —Regeneration in Unicellular Animal. (Stentor.) A., animal divided into three pieces, each containing a fragment of the nucleus; B., the fragment shortly afterward; C., after twenty-four hours, each regenerated into a perfect animal. (Wilson.)

its innumerable variously functioning cells. The study of the processes of digestion, of the changes in muscle and nerve cells leads finally to the examination of the functions of gland, muscle, ganglion and brain.

CHAPTER VII

ORGANIC FUNCTIONS

The facts dealing with the physiology of organisms, the activities associated with that which we call life are often designated Organic Functions. The terms animal physiology, plant physiology and human physiology are in common use and often suggest to the lay reader that the functions or workings of the organs of plants, animals or man are quite distinct, so much so as to require discussion in different treatises. This is true only as a matter of detail, for in the past fifty years it has been made evident that in general principles all living things are fundamentally similar. One of the most important summaries of this similarity is Huxley's famous essay, 'The Border Territory Between the Animal and Vegetable Kingdoms,' written in 1876, extracts from which follow.

In the second edition of the 'Règne Animal,' published in 1828, Cuvier devotes a special section to the 'Division of Organised Beings into Animals and Vegetables,' in which the question is treated with that comprehensiveness of knowledge and clear critical judgment which characterize his writings and justify biologists in regarding them as representative expressions of the most extensive, if not the profoundest, knowledge of his time. He affirms that living beings have been subdivided from the earliest times into animated beings, which possess sense and motion, and inanimated beings, which are devoid of these functions and simply vegetable.

Altho the roots of plants direct themselves toward moisture and their leaves toward air and light, altho the parts of some plants exhibit oscillating movements without any perceptible cause and the leaves of others retract when touched, yet none of these movements justify the ascription to plants of perception of will. From the mobility of animals Cuvier, with his characteristic partiality for teleological reasoning, reduces the necessity of the existence in them of an alimentary cavity, or reservoir of food, whence their nutrition may be drawn by vessels, which are a sort of internal roots; and, in the presence of this alientary cavity he naturally sees the primary and the most important distinction between animals and plants. logical reasoning, reduces the necessity of the existence in them of an alimentary cavity, or reservoir of food, whence their nutrition may be drawn by the vessels, which are a sort of internal roots; and in the presence of this alimentary cavity he naturally sees the primary and the most important distinction between animals and plants.

Following out his teleological argument, Cuvier remarks that the organization of this cavity and its appurtenances must needs vary according to the nature of the aliment and the operations which it has to undergo before it can be converted into substances fitted for absorption, while the atmosphere and the earth supply plants with juices ready prepared and which can be absorbed immediately. As the animal body required to be independent of heat and of the atmosphere, there were no means by which the motion of its fluids could be produced by internal causes. Hence arose the second great distinctive character of animals, or the circulatory system, which is less important than the digestive, since it was unnecessary, and therefore is absent, in the more simple animals.

Animals further needed muscles for locomotion and nerves for sensibility. Hence, says Cuvier, it was necessary that the chemical composition of the animal body should be more complicated than that of the plant; and it is

so, inasmuch as an additional substance—nitrogen—enters into it as an essential element; while in plants nitrogen is only accidentally joined with the three other fundamental constituents of organic beings—carbon, hydrogen and oxygen. Indeed, he afterward affirms that nitrogen is peculiar to animals, and herein he places the third distinction between the animal and the plant. The soil and the atmosphere supply plants with water composed of hydrogen and oxygen and carbonic acid containing carbon and oxygen. They retain the hydrogen and the carbon, exhale the superfluous oxygen and absorb little or no nitrogen. The essential character of vegetable life is the exhalation of oxygen, which is effected through the agency of light. Animals, on the contrary, derive their nourishment either directly or indirectly from plants. They get rid of the superfluous hydrogen and carbon and accumulate nitrogen. The relations of plants and animals to the atmosphere are therefore inverse. The plant withdraws water and carbonic acid from the atmosphere, the animal contributes both to it. Respiration—that is, the absorption of oxygen and the exhalation of carbonic acid—is the specially animal function of animals and constitutes their fourth distinctive character.

Thus wrote Cuvier in 1828. But in the fourth and fifth decades of this century the greatest and most rapid revolution which biological science has ever undergone was effected by the application of the modern microscope to the investigation of organic structure, by the introduction of exact and easily manageable methods of conducting the chemical analysis of organic compounds and finally by the employment of instruments of precision for the measurement of the physical forces which are at work in the living economy.

That the semi-fluid contents (which we now term protoplasm) of the cells of certain plants, such as the Charae, are in constant and regular motion was made out by Bonaventura Corti a century ago; but the fact, important as it

was, fell into oblivion and had to be rediscovered by Treviranus in 1807. Robert Brown noted the more complex motions of the protoplasm in the cells of Tradescantia in 1831, and now such movements of the living substance of plants are well known to be some of the most widely prevalent phenomena of vegetable life.

Agardh and other of the botanists of Cuvier's generation who occupied themselves with the lower plants had observed that, under particular circumstances, the contents of the cells of certain water-weeds were set free and moved about with considerable velocity and with all the appearances of spontaneity as locomotive bodies, which, from their similarity to animals of simple organization, were called 'zoospores.' Even as late as 1845, however, a botanist of Schleiden's eminence dealt very skeptically with these statements, and his skepticism was the more justified since Ehrenberg in his elaborate and comprehensive work on the infusoria, had declared the greater number of what are now recognised as locomotive plants to be animals.

"At the present day," writes Huxley, "innumerable plants and free plant cells are known to pass the whole or part of their lives in an actively locomotive condition, in nowise distinguishable from that of one of the simpler animals, and while in this condition their movements are, to all appearances, as spontaneous—as much the product of volition—as those of such animals.

"Hence the teleological argument for Cuvier's first diagnostic character—the presence in animals of an alimentary cavity, or internal pocket, in which they can carry about their nutriment—has broken down, so far, at least, as his mode of stating it goes. And, with the advance of microscopic anatomy, the universality of the fact itself among animals has ceased to be predicable. Many animals of even complex structure which live parasitically within others are wholly devoid of an alimentary cavity. Their food is provided for them, not only ready cooked but ready

digested, and the alimentary canal, become superfluous, has disappeared, and, again, the males of most Rotifers have no digestive apparatus. Finally amid the lowest forms of animal life the speck of gelatinous protoplasm, which constitutes the whole body, has no permanent digestive cavity or mouth, but takes in its food anywhere and digests, so to speak, all over its body.

"But altho Cuvier's leading diagnosis of the animal from the plant will not stand a strict test, it remains one of the most constant of the distinctive characters of animals. And if we substitute for the possession of an alimentary cavity the power of taking solid nutriment into the body and there digesting it, the definition so changed will cover all animals, except certain parasites, and the few and exceptional cases of non-parasitic animals which do not feed at all. On the other hand, the definition thus amended will exclude all ordinary vegetable organisms. Cuvier himself practically gives up his second distinctive mark when he admits that it is wanting in the simpler animals.

"The third distinction is based on a completely erroneous conception of the chemical differences and resemblances between the constituents of animal and vegetable organisms, for which Cuvier is not responsible, as it was current among contemporary chemists. It is now established that nitrogen is as essential a constituent of vegetable as of animal living matter and that the latter is, chemically speaking, just as complicated as the former. Starchy substances, cellulose and sugar, once supposed to be exclusively confined to plants, are now known to be regular and normal products of animals. Amylaceous and saccharine substances are largely manufactured, even by the highest animals. Cellulose is widespread as a constituent of the skeletons of the lower animals and it is probable that amyloid substances are universally present in the animal organism, tho not in the precise form of starch.

"Moreover, altho it remains true that there is an inverse relation between the green plant in sunshine and the ani-

mal, in so far as under these circumstances the green plant decomposes carbonic acid and exhales oxygen while the animal absorbs oxygen and exhales carbonic acid, yet the exact researches of the modern chemical investigators of the physiological processes of plants have clearly demonstrated the fallacy of attempting to draw any general distinction between animals and vegetables on this ground. In fact, the difference vanishes with the sunshine, even in the case of the green plant, which in the dark absorbs oxygen and gives out carbonic acid like any animal. On the other hand, those plants, such as the fungi, which contain no chlorophyll and are not green, are always, so far as respiration is concerned, in the exact position of animals. They absorb oxygen and give out carbonic acid. Thus, by the progress of knowledge, Cuvier's fourth distinction between the animal and the plant has been as completely invalidated as the third and second, and even the first can be retained only in a modified form and subject to exceptions."

But has the advance of biology simply tended to break down old distinctions without establishing new ones? With a qualification, to be considered presently, the answer to this question is undoubtedly in the affirmative. The famous researches of Schwann and Schleiden in 1837 and the following years founded the modern science of histology or that branch of anatomy which deals with the ultimate visible structure of organisms as revealed by the microscope, and from that day to this the rapid improvement of methods of investigation and the energy of a host of accurate observers have given greater and greater breadth and firmness to Schwann's great generalization that a fundamental unity of structure obtains in animals and plants, and that, however diverse may be the fabrics or tissues of which their bodies are composed, all these varied structures result from the metamorphosis of morphological units (termed cells in a more general sense than that in which the word 'cells' was at first employed), which are not only similar in animals and in plants respec-

tively, but present a close resemblance when those of animals and those of plants are compared together.

"The contractility which is the fundamental condition of locomotion," continues Huxley, "has not only been discovered to exist far more widely among plants than was formerly imagined, but in the plants the act of contraction has been found to be accompanied, as Dr. Burdon Sanderson's interesting investigations have shown, by a disturbance of the electrical state of the contractile substance comparable to that which was found by Du Bois Reymond to be a concomitant of the activity of ordinary muscle in animals. Again, I know of no test by which the reaction of the leaves of the Sundew and of other plants to stimuli, so fully and carefully studied by Mr. Darwin, can be distinguished from those acts of contraction following upon stimuli, which are called 'reflex' in animals.

"On each lobe of the bilobed leaf of Venus flytrap are three delicate filaments which stand out at right angles from the surface of the leaf. Touch one of them with the end of a fine human hair and the lobes of the leaf instantly close together in virtue of an act of contraction of part of their substance, just as the body of a snail contracts into its shell when one of its 'horns' is irritated.

"The reflex action of the snail is the result of the presence of a nervous system in the animal. A molecular change takes place in the nerve of the tentacle, is propagated to the muscles by which the body is retracted, and causing them to contract, the act of retraction is brought about. Of course the similarity of the acts does not necessarily involve the conclusion that the mechanism by which they are effected is the same, but it suggests a suspicion of their identity which needs careful testing."

The results of inquiries into the structure of the nervous system of animals converge toward the conclusion that the nerve fibers, which have been regarded as ultimate elements of nervous tissue, are not such, but are simply the visible aggregations of vastly more attenuated filaments, the di-

ameter of which dwindles down to the limits of our present microscopic vision, greatly as these have been extended by modern improvements of the microscope, and that a nerve is, in its essence, nothing but a linear tract of specially modified protoplasm between two points of an organism—one of which is able to affect the other by means of the communication so established. Hence it is conceivable that even the simplest living being may possess a nervous system. And the question whether plants are provided with a nervous system or not thus acquires a new aspect and presents the histologist and physiologist with a problem of extreme difficulty, which must be attacked from a new point of view and by the aid of methods which have yet to be invented.

"Thus it must be admitted," he says again, "that plants may be contractile and locomotive; that, while locomotive, their movements may have as much appearance of spontaneity as those of the lowest animals, and that many exhibit actions comparable to those which are brought about by the agency of a nervous system in animals. And it must be allowed to be possible that further research may reveal the existence of something comparable to a nervous system in plants. So that I know not where we can hope to find any absolute distinction between animals and plants, unless we return to their mode of nutrition and inquire whether certain differences of a more occult character than those imagined to exist by Cuvier, and which certainly hold good for the vast majority of animals and plants, are of universal application.

"A bean may be supplied with water in which salts of ammonia and certain other mineral salts are dissolved in due proportion, with atmospheric air containing its ordinary minute dose of carbonic acid and with nothing else but sunlight and heat. Under these circumstances, unnatural as they are, with proper management, the bean will thrust forth its radicle and its plumule; the former will grow down into roots, the latter grow up into the stem and

leaves of a vigorous bean-plant, and this plant will, in due time, flower and produce its crop of beans just as if it were grown in the garden or in the field.

"The weight of the nitrogenous protein compounds, of the oily, starchy, saccharine and woody substances contained in the full-grown plant and its seeds will be vastly greater than the weight of the same substances contained in the bean from which it sprang. But nothing has been supplied to the bean save water, carbonic acid, ammonia, potash, lime, iron and the like in combination with phosphoric, sulphuric and other acids. Neither protein, nor fat, nor starch, nor sugar, nor any substance in the slightest degree resembling them has formed part of the food of the bean. But the weights of the carbon, hydrogen, oxygen, nitrogen, phosphorus, sulphur and other elementary bodies contained in the bean-plant and in the seeds which it produces are exactly equivalent to the weights of the same elements which have disappeared from the materials supplied to the bean during its growth. Whence it follows that the bean has taken in only the raw materials of its fabric and has manufactured them into bean-stuffs.

"The bean has been able to perform this great chemical feat by the help of its green coloring matter, or chlorophyll, for it is only the green parts of the plant which, under the influence of sunlight, have the marvelous power of decomposing carbonic acid, setting free the oxygen and laying hold of the carbon which it contains. In fact, the bean obtains two of the absolutely indispensable elements of its substance from two distinct sources. The watery solution, in which its roots are plunged, contains nitrogen but no carbon; the air, to which the leaves are exposed, contains carbon, but its nitrogen is in the state of a free gas, in which condition the bean can make no use of it, and the chlorophyll is the apparatus by which the carbon is extracted from the atmospheric carbonic acid, the leaves being the chief laboratories in which this operation is effected.

"The great majority of conspicuous plants are, as everybody knows, green, and this arises from the abundance of their chlorophyll. The few which contain no chlorophyll and are colorless are unable to extract the carbon which they require from atmospheric carbonic acid and lead a parasitic existence upon other plants, but it by no means follows, often as the statement has been repeated, that the manufacturing power of plants depends on their chlorophyll and its interaction with the rays of the sun. On the contrary, it is easily demonstrated, as Pasteur first proved, that the lowest fungi, devoid of chlorophyll or of any substitute for it as they are, nevertheless possess the characteristic manufacturing power of plants in a very high degree. Only it is necessary that they should be supplied with a different kind of raw material; as they cannot extract carbon from carbonic acid, they must be furnished with something else that contains carbon. Tartaric acid is such a substance, and if a single spore of the commonest and most troublesome of molds—'Penicillium'—be sown in a saucerful of water in which tartrate of ammonia, with a small percentage of phosphates and sulphates is contained, and kept warm, whether in the dark or exposed to light, it will in a short time give rise to a thick crust of mold, which contains many million times the weight of the original spore in protein compounds and cellulose. Thus we have a very wide basis of fact for the generalization that plants are essentially characterized by their manufacturing capacity—by their power of working up mere mineral matters into complex organic compounds.

"Contrariwise, there is a no less wide foundation for the generalization that animals, as Cuvier put it, depend directly or indirectly upon plants for the material of their bodies; that is, either they are herbivorous or they eat other animals which are herbivorous. But for what constituents of their bodies are animals thus dependent upon plants? Certainly not for their horny matter; nor for chondrin, the proximate chemical element of cartilage;

nor for gelatin; nor for syntonin, the constituent of muscle; nor for their nervous or biliary substances; nor for their amyloid matters; nor, necessarily, for their fats.

"It can be experimentally demonstrated that animals can make these for themselves. But that which they cannot make, but must in all known cases obtain directly or indirectly from plants, is the peculiar nitrogenous matter, protein. Thus the plant is the ideal proletariat of the living world—the worker who produces—the animal, the ideal aristocrat, who mostly occupies himself in consuming, after the manner of that noble representative of the line of Zähdarm, whose epitaph is written in 'Sartor Resartus.'

"Here is our last hope of finding a sharp line of demarcation between plants and animals, for, as I have already hinted, there is a border territory between the two kingdoms, a sort of no man's land, the inhabitants of which certainly cannot be discriminated and brought to their proper allegiance in any other way.

"Some months ago Professor Tyndall asked me to examine a drop of infusion of hay, placed under an excellent and powerful microscope, and to tell him what I thought some organisms visible in it were. I looked and observed, in the first place multitudes of 'Bacteria' moving about with their ordinary intermittent spasmodic wriggles. As to the vegetable nature of these, there is now no doubt. Not only does the close resemblance of the 'Bacteria' to unquestionable plants, such as the 'Oscillartoria' and the lower forms of 'Fungi,' justify this conclusion, but the manufacturing test settles the question at once. It is only needful to add a minute drop of fluid containing 'Bacteria' to water in which tartrate, phosphate and sulphate of ammonia are dissolved, and in a very short space of time the clear fluid becomes milky by reason of their prodigious multiplication which, of course, implies the manufacture of living bacterium-stuff out of these merely saline matters.

"But other active organisms, very much larger than the

bacteria, attaining, in fact, the comparatively gigantic dimensions of one-three-thousandth of an inch or more, incessantly crossed the field of view. Each of these had a body shaped like a pear, the small end being slightly incurved and produced into a long curved filament, or cilium, of extreme tenuity. Behind this, from the concave side of the incurvation, proceeded another long cilium, so delicate as to be discernible only by the use of the highest powers and careful management of the light. In the center of the pear-shaped body a clear, round space could occasionally be discerned, but not always, and careful watching showed that this clear vacuity appeared gradually and then shut up and disappeared suddenly at regular intervals. Such a structure is of common occurrence among the lowest plants and animals and is known as a contractile vacuole.

"The little creature thus described sometimes propelled itself with great activity, with a curious rolling motion, by the lashing of the front cilium, while the second cilium trailed behind; sometimes it anchored itself by the hinder cilium and was spun around by the working of the other, its motions resembling those of an anchor buoy in a heavy sea. Sometimes, when two were in full career toward one another, each would appear dexterously to get out of the other's way; sometimes a crowd would assemble and jostle one another with as much semblance of individual effort as a spectator on the Grands Mulets might observe with a telescope among the specks representing men in the valley of Chamounix.

"The spectacle, tho always surprising, was not new to me. So my reply to the question put to me was that these organisms were what biologists call 'Monads,' and tho they might be animals, it was also possible that they might, like the 'Bacteria,' be plants. My friend received my verdict with an expression which showed a sad want of respect for authority. He would as soon believe that a sheep was a plant. Naturally piqued by this want of faith, I have thought a good deal over the matter, and as I still rest

in the lame conclusion I originally expressed must even now confess that I cannot certainly say whether this creature is an animal or a plant."

Thus in the question of making proteid there are all gradations from plants able to make proteid from inorganic matter to plants which are as much animal as vegetable in structure, but are animal in the dependence on other organisms for their food. The singular circumstance observed by Meyer that the torula of yeast, tho an indubitable plant, still flourishes most vigorously when supplied with the complex nitrogenous substance pepsin, the probability that the potato blight is nourished directly by the protoplasm of the potato-plant, and the wonderful facts which have recently been brought to light respecting insectivorous plants all favor this view and tend to the conclusion that the difference between animal and plant is one of degree rather than of kind and that the problem whether, in a given case, an organism is an animal or a plant may be essentially insoluble.

This conception that animals and plants differ not in kind has been of great importance in the development of biology as a unified science of life. But, altho the differences in the organic functions are of degree rather than of kind, it is true that the differences of degree are clear enough, except in certain unicellular organisms which are on the border line, to enable us to distinguish between animals and plants and to make it convenient to divide physiology, the science of function, into plant and animal physiology. These differences will be clearer by adding to Huxley's general comparison of plants and animals a concrete comparison of an animal and a plant. For this purpose one of Huxley's most famous students, T. Jeffery Parker, chose the unicellular animal 'Amoeba' and the unicellular plant 'Haematococcus,' also known as 'Sphaerella.' Both of these live in water. In their nutrition there are some differences, for Amoeba can take in solid food (other small animals and plants), formed of protoplasm as

complex as its own. These it breaks up by means of digestive juices into soluble proteids and then recombines them to form its own protoplasm. Haematococcus has not this ability to take in solid food; it never feeds in the ordinary sense of the word. Nevertheless it must take in food in some way or other or the decomposition of its protoplasm would soon bring it to an end. The water in which it lives is never pure, but always contains certain mineral

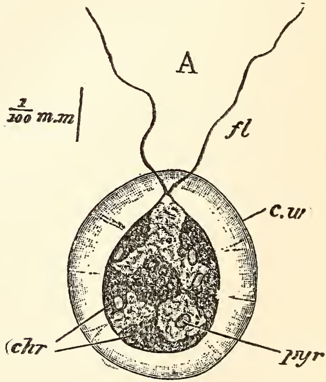


Fig. 11 —Hæmatococcus.

c. w., cell wall; chr., chromatophores; pyr., pyrenoids; fl., flagella. (Parker.)

salts in solution, especially nitrates, ammonia salts and often sodium chloride or common table salt. These salts, being crystalloids, can and do diffuse into the water of the organism so that we may consider its protoplasm to be constantly permeated by a very weak saline solution, the most important elements contained in which are oxygen, hydrogen, nitrogen, potassium, sodium, calcium, sulphur

and phosphorus. It must be remarked, however, that the diffusion of these salts does not take place in the same uniform manner as it would through parchment or other dead membrane. The living protoplasm has the power of determining the extent to which each constituent of the solution shall be absorbed.

"If water containing a large quantity of Haematococcus is exposed to sunlight minute bubbles are found to appear in it, and these bubbles, if collected and properly tested, are found to consist largely of oxygen. Accurate chemical analysis has shown that this oxygen is produced by the decomposition of the carbon dioxide contained in solution in rain-water, and indeed in all water exposed to the air, the gas, which is always present in small quantities in the atmosphere, being very soluble in water.

"As the carbon dioxide is decomposed in this way, its oxygen being given off, it is evident that its carbon must be retained. As a matter of fact, it is retained by the organism, but not in the form of carbon. In all probability a double decomposition takes place between the carbon dioxide absorbed and the water of organization, the result being the liberation of oxygen in the form of gas and the simultaneous production of some extremely simple form of carbohydrate—*i.e.*, some compound of carbon, hydrogen and oxygen, with a comparatively small number of atoms to the molecule.

"The next step seems to be that the carbohydrate thus formed unites with the ammonia salts or the nitrates absorbed from the surrounding water, the result being the formation of some comparatively simple nitrogenous compound. Then further combinations take place, substances of greater and greater complexity are produced, sulphur from the absorbed sulphates enters into combination and proteids are formed. From these finally fresh living protoplasm arises.

"From the foregoing account, which only aims at giving the very briefest outline of a subject as yet imperfectly

understood, it will be seen that, as in Amoeba, the final result of the nutritive process is the manufacture of protoplasm, and that this result is attained by the formation of various substances of increasing complexity. But it must be noted that the steps in the process of constructive metabolism are widely different in the two cases. In Amoeba we start with living protoplasm—that of the prey which is killed and broken up into diffusible proteids, these being afterward recombined to form new molecules of the living protoplasm of Amoeba. So that the food of Amoeba is, to begin with, as complex as itself, and is broken down by digestion into simpler compounds, these being afterward recombined into more complex ones. In Haematococcus, on the other hand, we start with extremely simple compounds, such as carbon dioxide, water, nitrates, sulphates, etc. Nothing which can be properly called digestion—*i.e.*, a breaking up and dissolving of the food, takes place, but its various constituents are combined into substances of gradually increasing complexity, protoplasm, as before, being the final result.

"To express the matter in another way: Amoeba can only make protoplasm out of proteids already formed by some other organism; Haematococcus can form it out of simple liquid and gaseous inorganic materials.

"Speaking generally, it may be said that these two methods of nutrition are respectively characteristic of the two great groups of living things. Animals require solid food containing ready-made proteids and cannot build up their protoplasm out of simpler compounds. Green plants—*i.e.*, all the ordinary trees, shrubs, weeds, etc.—take only liquid and gaseous food and build up their protoplasm out of carbon dioxide, water and mineral salts. The first of these methods of nutrition is conveniently distinguished as holozoic, or wholly-animal, the second as holophytic, or wholly-vegetal.

"It is important to note that only those plants or parts of plants in which chlorophyll is present are capable of

holophytic nutrition. Whatever may be the precise way in which the process is effected, it is certain that the decomposition of carbon dioxide which characterizes this form of nutrition is a function of chlorophyll, or to speak more accurately, of chromatophores, since there is reason for thinking that it is the protoplasm of these bodies, and not the actual green pigment, which is the active agent in the process.

"Moreover, it must not be forgotten that the decomposition of carbon dioxide is carried on only during daylight, so that organisms in which holophytic nutrition obtains are dependent upon the sun for their very existence. While Amoeba derives its energy from the breaking down of the proteids in its food, the food of Haematococcus is too simple to serve as a source of energy, and it is only by the help of sunlight that the work of constructive metabolism can be carried on. This may be expressed by saying that Haematococcus, in common with other organisms containing chlorophyll, is supplied with kinetic energy (in the form of light or radiant energy) directly by the sun.

"As in Amoeba, destructive metabolism is constantly going on, side by side with constructive. The protoplasm becomes oxidized, water, carbon dioxide and nitrogenous waste matters being formed and finally got rid of. Obviously then absorption of oxygen must take place, or in other words, respiration must be one of the functions of the protoplasm of Haematococcus as of that of Amoeba. In many green—*i.e.,* chlorophyll containing—plants this has been proved to be the case; respiration—*i.e.,* the taking in of oxygen and giving out of carbon dioxide—is constantly going on, but during daylight is obscured by the converse process, the taking in of carbon dioxide for nutritive purposes and the giving out of the oxygen liberated by its decomposition. In darkness, when this latter process is in abeyance, the occurrence of respiration is more readily ascertained."

CHAPTER VIII

LIFE PROCESSES

NUTRITION thus, as has been pointed out, makes it possible to classify most organisms as animals or plants. Yet there are many unicellular forms in which both kinds of nutrition go on at the same time; that is, the forms may possess a mouth for the ingestion of solid food and green coloring matter, chlorophyll, for the manufacture of starchy food from gaseous matter.

Many of the lowest forms of life have long been puzzles and the beginner in biological study is surprised to find them described in text-books of both botany and zoölogy. The fact is that they are on the border line, are neither plants nor animals but simply organisms. Since they cannot be classified, it is necessary that they be listed both under botany and zoölogy, in order to make sure that they will not be omitted entirely. Because of these uncertain forms of life, Haeckel proposed once to include all one-celled animals and plants in a third kingdom to be called Protista (meaning the first of all life).

Parker's definition of animals and plants, based on the foregoing considerations, is convenient for distinguishing between animals and plants in all cases except the doubtful unicellar forms. He says:

"Animals are organisms of fixed and definite form, in which the cell-body is not covered with a cellulose wall. They ingest solid proteinaceous food, their nutritive processes result in oxidation, they have a definite organ of excretion and are capable of automatic movement.

"Plants are organisms of constantly varying form in which the cell-body is surrounded by a cellulose wall; they cannot ingest solid food, but are nourished by a watery solution of nutrient materials. If chlorophyll is present, the carbon dioxide of the air serves as a source of carbon, nitrogen is obtained from simple salts and the nutritive processes result in deoxidation; if chlorophyll is absent, carbon is obtained from sugar or some similar compound, nitrogen either from simple salts or from proteids, and the process of nutrition is one of oxidation. There is no spe-

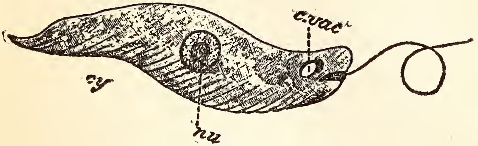


Fig. 12 —Euglena viridis.

Contains chlorophyll, therefore it can manufacture food as a plant does; it also has a simple mouth, therefore it can ingest solid food as an animal does; its nutrition is both holophytic and holozoic; magnified. (Kent.) nu., nucleus; c. vac., contractile vacuole.

cial excretory organ, and, except in the case of certain reproductive bodies, there is usually no locomotion."

The important point to recognise is that these boundaries are artificial and that there are no scientific frontiers in Nature. As in the liquefaction of gases, there is a 'critical point' at which the substance under experiment is neither gaseous nor liquid; as in a mountainous country, it is impossible to say where mountain ends and valley begins; as in the development of an animal, it is futile to argue about the exact period when, for instance, the egg becomes a tadpole or the tadpole a frog, so in the case under discussion. The distinction between the higher plants and animals is perfectly sharp and obvious, but when the two groups are traced downward they are found gradually to

merge, as it were, into an assemblage of organisms which partake of the characters of both kingdoms and cannot without a certain violence be either included in or excluded from either. When any given 'protist' has to be classified the case must be decided on its individual merits; the organism must be compared in detail with all those which resemble it closely in structure, physiology and life history, and then a balance must be struck and the doubtful form placed in the kingdom with which it has, on the whole, most points in common.

It will no doubt occur to the reader that, on the theory of evolution, the fact of the animal and vegetable kingdoms being related to one another like two trees united at the roots may be accounted for by the hypothesis that the earliest organisms were protists and that from them animals and plants were evolved along divergent lines of descent. And in this connection the fact that some bacteria —the simplest organisms known and devoid of chlorophyll—may flourish in solutions wholly devoid of organic matter is very significant.

The lower plants and animals referred to above are so far from everyday observation and hence so unfamiliar that to most people the comparison made will mean little in terms of ordinary green flowering plants and common vertebrate animals. In order to emphasize the fundamental similarity of organic function in higher and lower animals and plants, let us compare any higher plant —*e.g.*, a bean plant with a higher animal, *e.g.*, frog or even man. In each the life is the sum total of a series of definite processes—nutrition or food supply, circulation, metabolism, excretion, oxygenation (part of respiration), movement, irritability (nervous activity) and reproduction. In turn these will be compared for the animal and the plant, following in part the comparisons of certain animals and plants by Sedgwick and Wilson and others. These comparisons will, however, be translated into terms applicable to any species of higher plants or animals.

In the nutrition of the animal the most essential and characteristic part of the food supply is derived from vegetable or animal matter in the form of various organic compounds, of which the most important are proteids (protoplasm, albumen, etc.), carbohydrates (starch, cellulose) and fats. These materials are used by the animal in the manufacture of new protoplasm to take the place of that which has been used up. It is, however, impossible for the animal to build these materials directly into the substance of its own body. They must first undergo certain preparatory chemical changes known collectively as digestion, and only after the completion of this process can all the food be absorbed into the circulation.

For this purpose the food is taken not into the body proper, but into a kind of tubular chemical laboratory called the alimentary canal, through which it slowly passes, being subjected meanwhile to the action of certain chemical substances or reagents, known as digestive ferments. These substances, which are dissolved in a watery liquid to form the digestive fluid, are secreted by the walls of the alimentary tube. Through their action the solid portions are liquefied and the food is rendered capable of absorption into the body proper.

The food supply of the higher plant, like that of the animal, is the source of the required matter and energy, but unlike that of the animal, it is not chiefly an income of foods, but only of the raw materials of food. Matter enters the plant in the liquid or gaseous form by diffusion, both from the soil through the roots (liquids) and from the atmosphere through the leaves (gases). We have here the direct absorption into the body proper of food-stuffs precisely as the animal takes in water and oxygen. Energy enters the plant, to a small extent, as the potential energy of food-stuffs, but comes in principally as the kinetic energy of sunlight absorbed in the leaves.

Of the substances the solids (salts, etc.) must be dissolved in water before they can be taken in. Water and

dissolved salts continually pass by diffusion from the soil into the roots, where together they constitute the sap. The sap travels throughout the whole plant, the main tho not the only cause of movement being the constant transpiration (evaporation) of watery vapor from the leaves, especially through the stomata. The gaseous matters (carbon dioxide, oxygen, nitrogen) enter the plant mainly by diffusion from the atmosphere, are dissolved by the sap in the leaves and elsewhere and thus may pass to every portion of the plant.

The green plant owes its power of absorbing the energy of sunlight to the chlorophyll-bodies or chromatophores, for plants which, like fungi, etc., are devoid of chlorophyll, are unable thus to acquire energy. Entering the chlorophyll-bodies, the kinetic energy of sunlight is applied to the decomposition of carbon dioxide and water. After passing through manifold but imperfectly known processes, the elements of these substances finally reappear as starch, often in the form of granules embedded in the chlorophyll-bodies and free oxygen, most of which is returned to the atmosphere. Thus the leaf of a green plant in the light is continually absorbing carbon dioxide and giving forth free oxygen.

Carbon dioxide and water contain no potential energy, since the affinities of their constituent elements are completely satisfied. Starch, however, contains potential energy, since the molecule is relatively unstable—*i.e.*, capable of decomposition into simpler, stabler molecules in which stronger affinities are satisfied. And this is due to the fact that in the manufacture of starch in the chlorophyll-bodies the kinetic energy of sunlight was expended in lifting the atoms into position of vantage, thus endowing them with energy of position. In this way some of the radiant and kinetic energy of the sun comes to be stored up as potential energy in the starch. In short, the green plant is able by coöperation with sunlight to use simple raw materials (carbon dioxide, water, oxygen, etc.) poor in

energy or devoid of it, and out of them to manufacture food—*i.e.,* complex compounds rich in available potential energy. This power is possessed by green plants alone; all other organisms being dependent for energy upon the potential energy of ready-made food. This must, in the first instance, be provided for them by green plants, and hence without chlorophyll-bearing plants, animals (and colorless plants as well) apparently could not long exist.

The plant absorbs also a small amount of kinetic energy, independently of the sunlight, in the form of heat. This, however, is probably not a source of vital energy, but only contributes to the maintenance of the body temperature.

Food (starch) thus produced in the green leaves of higher plants and the inorganic foods (water, nitrites or nitrates and various mineral substances in solution in water) furnish the materials and energy required for the life and growth of the plant.

The circulatory system distributes these foods. In animals foods prepared for absorption in the stomach and intestine (by digestion) are absorbed by the circulating liquids (blood and lymph) and transported to all cells of the animal body. In the plant the inorganic matter in water from the soil are absorbed by the roots and carried up definite tubes in the woody part of the stem. The causes of this ascent are not clear, but root-pressure due to osmosis, capillary action and evaporation from the leaves are factors. Just as the solid food of animals must be digested in preparation for absorption, so starch manufactured in the leaves must be digested (dissolved) before it can be transported. This is done by diastase, an enzyme of plant cells. The change is from starch to a sugar capable of diffusion. Dissolved in water, the sugar is transported down delicate tubes, chiefly in the growing bark region of the stem. It is clear that there are upward and downward currents of water containing food (comparable to blood of an animal), but no system of complete circulation as in the blood ves-

sels of a higher animal. However, the result in distributed food is the same in the plant and in the animal.

In the cells the foods undergo metabolic changes. In an animal the foods in the circulating liquids, blood and lymph, are selected and absorbed by the cells. Only proteid foods form new protoplasm and even of proteids only a limited amount, seventy-five to one hundred grams a day for a man, is built into new protoplasm. The excess undergoes oxidation and forms nitrogen excretions. The foods containing only the elements carbon, hydrogen and oxygen (fats and carbohydrates) are directly oxidized to excretions and, lacking nitrogen, cannot serve for making new animal protoplasm. Fat and carbohydrate foods, then, never become living matter. They may be stored, especially as fat, until needed for oxidation to supply energy. The building up of the protoplasm from proteids is anabolism, constructive metabolism. The destruction of protoplasm, excess proteids or the fat and carbohydrate foods is katabolism, destructive metabolism. Katabolism is probably due to enzyme action, but the final result is chiefly carbon dioxide and water, which could be deiived by the ordinary chemical evolution of protoplasm, proteid, sugar, starch or fats.

In the plant, starch, as has been seen, is first formed in the chlorophyll-bodies. But the formation of starch, all-important as it is, is after all only the manufacture of food as a preliminary to the real processes of nutrition. These processes must take place everywhere in ordinary protoplasm, for it is here that oxidation occurs and the need for a renewal of matter and energy consequently arises. Sooner or later the starch grains are changed into a kind of sugar (glucose), which, unlike starch, dissolves in the sap and may thus be easily transported to all parts of the plant. Wherever there is need for new protoplasm, whether to repair previous waste or to supply materials for growth, after absorption into the cells the elements of the starch (or glucose) are, by the living protoplasm, in some

unknown way combined with nitrogen and sulphur (probably also with salts, water, etc.) to form proteid matter. The particles of this newly formed compound are incorporated into the protoplasm.

If a larger quantity of starch is formed in the chlorophyll-bodies than is immediately needed by the protoplasm for purposes of repair or growth, it may be reconverted into starch after journeying as glucose through the plant and be laid down as "reserve starch" in the cells of root or stem or elsewhere. Apparently when this reserve supply is finally needed at any point in the plant, it is again changed to glucose and transported thither. It is probable that new leaves and new tissues generally are always formed in part from this reserve starch.

In the plant as in the animal metabolism must consist of anabolic and katabolic processes. The construction in the cells of new proteid from the absorbed carbohydrate and the materials from the soil is true anabolism. It is also clear that katabolism or oxidation for the liberation of energy occurs as in animals, but this process is slower. Probably foods containing carbon, hydrogen and oxygen are the sources of energy in the higher plants as in animals.

In both plants and animals simple waste substances result from the katabolic processes in the cells. In the animal carbon dioxide, water and nitrogen compounds are the chief excretions. They are absorbed by the circulating liquids and carried to the eliminating organs, lungs and kidneys chiefly, for elimination. In the higher plants the excretions are carbon dioxide, which escapes through the epidermis of root, stem and leaf and through the stomata; water which is lost by evaporation, especially from the leaf surface through the stomata; excretions which are lost by osmosis through the roots and the accumulated but useless mineral substances which are eliminated by leaf fall.

In both animals and plants oxygen is essential to the katabolic part of metabolism. Hence oxygen must be sup-

plied to the cells. Oxygenation is the term used to denote the oxygen-supplying part of respiration; the other part of respiration, elimination of carbon dioxide, has been treated under excretions. In the animal oxygen is absorbed by the blood, in excess by the hemoglobin of the red cells of the blood and later is absorbed from the blood and lymph by all the living cells. In the plant also oxygen is absorbed through the epidermis and stomata from the air. This process is, however, obscured during the day because of the oxygen freed in the manufacture of starch which goes on at that time. Probably this freed oxygen is used for the purpose of oxygenation, but more is freed in the photosynthetic process than is needed for oxygenation and hence the excess oxygen is eliminated while starch manufacture is in process.

In comparing a higher animal and a green plant confusion must be avoided regarding the part played by oxygen and carbon dioxide in true respiration with the part played by the same substances in starch formation (photosynthesis). In non-green plants like the Indian pipe and mushrooms the breathing of oxygen and the excretion of carbon dioxide are as in the animal. This is true also of green plants in darkness and even in the light of all parts of green plants except the chlorophyll-bodies. These constitute a sort of extra mechanism, enabling green plants to make their own carbohydrate food. Imagine a higher animal with an attachment for turning the carbon dioxide and water excreted back to starch usable as food and the comparison of the green plant and the animal would be complete.

The power of movement or locomotion is curiously thought of as peculiar to animals, but biologists know dozens of examples of movement in plants. Some of the lower plants possess the power of locomotion and even in plants as high as mosses and ferns there is a locomotion of the male germ-cells. Among the flowering plants there is no actual locomotion, but there are numerous forms of

movement. Most striking perhaps are the so-called "sleep-movements" of plants by means of which the leaves of some plants—*e.g.*, the oxalis, bean, clover, locust and others—can assume decidedly different positions at night from those which they occupy by day; the movements of the sensitive plant (Mimosa) when "shocked" by touch or in

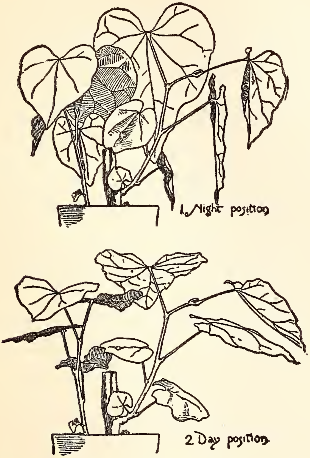


Fig. 13 —REDBUD, 'CERCIS CANADENSIS,' SHOWING DAY AND NIGHT POSITIONS OF THE LEAVES.

other ways, and the movements of the leaves of the Venus flytrap (Dionea), which close with a quick jerk when the sensitive hairs with which they are bordered are stimulated.

It is in nervous functions that the most striking differ-

ence between the animal and the plant is to be found. Plants have no true nervous system, nevertheless irritability or response to stimulus is well marked in many plants. It would carry us far beyond the limits of this volume to trace satisfactorily the powers of plants to respond to stimuli of gravity, light, heat, water, electricity, chemicals, contact, injury and so on. Suffice it to say that the total effect of such responses is for the plant equal to that of the nervous system for the animal.

Reproduction is a most important function. The life of every organic species runs in regularly

Fig. 14 —Sensitive Plant, Before and After 'Alarm.' (Duchartre.)

recurring cycles, for every individual life has its limit. In youth the constructive processes preponderate over the destructive and the organism grows. The normal adult attains a state of apparent physiological balance in which the processes of waste and repair are approximately equal. Sooner or later, however, this balance is disturbed. Even tho the organism escapes every injury or special disease, the constructive process falls behind the destructive,

old age ensues and the individual dies from sheer inability to live. Why the vital machine should thus wear out is a mystery, but that it has a definite cause and meaning is indicated by the familiar fact that the span of natural life varies with the species; man lives longer than the dog, the elephant longer than man.

It is a wonderful fact that living things have the power to detach from themselves portions or fragments of their own bodies endowed with fresh powers of growth and development and capable of running through the same cycle as the parent. There is therefore an unbroken material (protoplasmic) continuity from one generation to another that forms the physical basis of inheritance and upon which the integrity of the species depends. As far as known, living things never arise save through this process. In other words, every mass of existing protoplasm is the last link in an unbroken chain that extends backward in the past to the first origin of life.

The detached portions of the parent that are to give rise to offspring are sometimes masses of cells, as in the separation of branches or buds among plants, but more commonly they are single cells, known as germ-cells, like the eggs of animals and the spores of ferns and mosses. Only the germ-cells (which may conveniently be distinguished from those forming the rest of the body or the somatic cells) escape death, and that only under certain conditions.

All forms of reproduction fall under one or the other of two heads, viz., agamogenesis (asexual reproduction) or gamogenesis (sexual reproduction). In the former case the detached portion (which may be either a single cell or a group of cells) has the power to develop into a new individual without the influence of other living matter. In the latter, the detached portion, in this case always a single cell (ovum, oösphere, etc.), is acted upon by a second portion of living matter, likewise a single cell, which in most cases has been detached from the body of another

individual. The germ is called the female germ-cell, the cell acting upon it the male germ-cell, and in the sexual process the two fuse together (fertilization, impregnation) to form a single new cell endowed with the power of developing into a new individual. In some organisms (*e.g.,* the yeast-plant and bacteria) only agamogenesis has been observed; in others (*e.g.,* vertebrates) only gamogenesis; in others still both processes take place as in many higher plants.

The earthworm, for example, is not known to multiply by a natural process of agamogenesis. It possesses in a high degree, however, the closely related power of regeneration, for if a worm be cut transversely into two pieces the anterior piece will usually make good or regenerate the missing portion, while the posterior piece may regenerate the anterior region. Thus the worm can to a certain limited extent be artificially propagated, like a plant, by cuttings, a process closely related to true agamogenesis. Its usual and normal mode of reproduction is by gamogenesis; that is, by the formation of male germ-cells (spermatozoa) and female germ-cells (ova). In higher animals the two kinds of germ-cells are produced by different individuals of opposite sex. The earthworm, on the contrary, is hermaphrodite or bisexual; every individual is both male and female, producing both eggs and spermatozoa.

As in the animal so in the plant, whether the individual dies or not, ample provision against the death of the race is made in the act of reproduction. Altho reproduction appears to be useless to the individual and even entails upon it serious annual losses of matter and energy, yet to this function every part of the plant directly or indirectly contributes. The reproductive germs are carefully prepared, are provided with a stock of food sufficient for the earliest stages of development, and are endowed with the peculiar powers and limitations of each species which influence their life history at every step and are by them transmitted in turn to their descendants. They are living

portions of the parent detached for reproductive purposes and they contain a share of protoplasm directly descended from the original protoplasm from which the parent came. In short, reproduction is the supreme function of the plant.

As in the animal, reproduction in the higher plants is by the process of gamogenesis. Male germ-cells and female germ-cells are formed in separate organs. In many of the higher plants these organs are both found in the same individual, but often they are produced by different individuals of opposite sex. Agamogenesis, or asexual reproduction, also takes place in many higher plants by means of runners, buds, bulbs, tubers, etc., but in most of these cases provision is made for sexual reproduction also.

In relation to the environment animals and plants are masses of living matter occupying definite positions in space and time and existing amid certain definite and characteristic physical surroundings which constitute their "environment." As ordinarily understood the term environment applies only to the immediate surroundings of the animal and plant. Strictly speaking, however, the environment includes everything that may in any manner act upon the organisms—that is, the whole universe outside them. For they are directly and profoundly affected by rays of light and heat that travel to them from the sun; they are extremely sensitive to the alternations of day and night and the seasons of the year; they are acted on by gravity; and to all these, as well as to more immediate influence, they make definite responses.

The body of the animal is a complicated piece of mechanism constructed to perform certain definite actions. But every one of these actions is in one way or another dependent upon the environment and directly or indirectly relates to it. At every moment of its existence the organism is acted on by its environment; at every moment it reacts upon the environment, maintaining with it a constantly shifting state of equilibrium which finally gives way only when the life of the animal draws to a close.

The action of the environment upon the animal has been sufficiently stated. It remains to point out the changes worked by the animal on the environment. These changes are of two kinds, mechanical (or physical) and chemical. The general effect of the metabolism of the animal is the destruction by oxidation of organic matter; that is, matter originally taken from the environment in the form of complex proteids, fats, and carbohydrates is returned to it in the form of simpler and more highly oxidized substances, of which the most important are carbon dioxide and water (both inorganic substances). This action furthermore is accompanied by a dissipation of energy—that is, a conversion of potential into kinetic energy.

On the whole, therefore, the action of the animal upon the environment is that of an oxidizing agent, a reducer of complex compounds to simpler ones, and a dissipator of energy.

The actions of the environment upon the plant have been sufficiently dwelt upon. It still remains, however, to consider the actions of the plant upon the environment. These are partly physical, but mainly chemical. By pushing its stems and leaves into the air and slowly thrusting its roots through the soil, the atmosphere and the earth are alike displaced. But it is by its chemical activity that it most profoundly affects its environment. Absorbing from the latter water, salts, carbon dioxide, and other simple substances, as well as sunlight, it produces with them a remarkable metamorphosis. It manufactures from them as raw materials organic matter in the shape of starch, fats, and even proteids. These it gives back to the environment in some measure during life, and surrenders wholly after sudden death. But the most striking fact is that the plant is on the whole constructive and capable of producing and accumulating compounds rich in energy and in this respect it is unlike the animal.

Thus, while animals are destroyers of energized com-

pounds, green plants are producers of them. Animals, therefore, in the long run, are absolutely dependent on plants; and animals and colorless plants alike upon green plants. But it must never be forgotten that most plants are enabled to manufacture organic from inorganic matter by virtue of the chlorophyll which they contain. Without this they are powerless in this respect.

It is evident that to the superficial observer the plant and animal seem to have little or nothing in common, except that both are what we call alive. But whoever has studied the preceding pages must have perceived beneath manifold differences of detail a fundamental likeness between the plant and animal, not only in the substantial identity of the living matter in the two but also in the construction of their bodies and in the processes by which they come into existence. "Each arises from a single cell," to quote Sedgwick and Wilson, "which is the result of the union of two differently constituted cells, male and female. In both the primary cell multiplies and forms a mass of cells, at first nearly similar but afterward differentiated in various directions to enable them to perform different functions—*i.e.*, to effect a physiological division of labor. In both, the tissues thus provided are associated more or less closely into distinct organs and systems, among which the various operations of the body are distributed. And in both the ultimate goal of individual existence is the production of germ-cells which form the starting-point of new and similar cycles.

"This fundamental likeness extends also to most of the actions (physiology) of the two organisms. Both possess the power of adapting themselves to the environments in which they live. Both take in various forms of matter and energy from the environment, build them up into their own living substance, and finally break down this substance more or less completely into simpler compounds by processes of internal combustion, setting free by this action the energy which maintains their vital activity.

And, sooner or later, both give back to the environment the matter and energy which they have taken from it. In other words, both effect an exchange of matter and of energy with the environment."

Nevertheless the plant and the animal differ. They differ widely in form, and the plant is fixed and relatively rigid, while the animal is flexible and mobile. The body of the plant is relatively solid; that of the animal contains numerous cavities. The plant absorbs matter directly through the external surface; the animal partly through the external and partly through an internal (alimentary) surface. The plant is able to absorb simple chemical compounds from the air and earth, and kinetic energy from sunlight; the animal absorbs, for the most part, complex chemical compounds and makes no nutritive use of the sun's kinetic energy. By the aid of this energy the plant manufactures starch from simple compounds, carbon dioxide and water; the animal lacks this power. The plant can build up proteids from the nitrogenous and other compounds of its food. And by manufacturing proteids within its living substance, the plant is relieved of the necessity of carrying on a process of digestion in order to render them diffusible for entrance into the body.

Still, great as these differences appear to be at first sight, all of them, with a single exception, fade away upon closer examination. This exception is the power of making foods. Plants and animals differ in form because their mode of life differs; but a wider study of biology reveals the existence of innumerable animals (corals, sponges, hydroids, etc.) which have a close superficial resemblance to plants, and of many plants which resemble animals, not only in form, but also in possessing the power of active locomotion. The stomach of the animal, as shown by its development, is really a part of the general outer surface which is folded into the body; and the animal, like the plant, therefore, really absorbs its income over its whole surface—oxygen through the general outer

surface, other food-matters through the infolded alimentary surface.

In like manner it is easy to show that not one of the differences between the plant and animal is fundamentally important save the power of making foods. The animal must have complex ready-made food, including proteid matter. So must the plant; but the plant is able to manufacture this complex food out of very simple compounds. In terms of energy, the animal requires ready-made food rich in potential energy; the plant, aided by the sun's energy, can manufacture food from matters devoid of energy. Hence it appears, broadly speaking, that the plant by the aid of solar energy is constructive, and stores up energy; the animal is destructive, and dissipates energy. And this difference becomes of immense importance in view of the fact that it is true in this respect of all green plants, as of all animals.

Even this difference, great as it is, is partly bridged over by colorless plants like yeast, molds, bacteria, etc., which have no chlorophyll, are therefore unable to use the energy of light, and hence must have energized food. But these organisms do not, like animals, require proteid food, being able to extract all needful energy from the simpler fats, carbohydrates, and even from certain salts. When it is considered that the distinctive peculiarities of animals can thus be reduced to the sole characteristic of dependence on proteid food, it cannot be doubted that the difference between plants and animals is of immeasurably less importance than their fundamental likeness, the more so when it is kept in mind that each of the principles of organic function will be found to apply to all animals including man himself and to all plants, however complex they may be.

CHAPTER IX

ORIGIN OF SPECIES OF PLANTS AND ANIMALS

THERE are in the museums of the world at the present time representatives of several hundred thousand—probably more than a million—kinds or species of plants and animals, and thousands of new species are being discovered and named each year. A single group of insects has classified under it more species than there are stars to be seen in the heavens with the unaided eye on a clear night. Aristotle knew about five hundred kinds of animals, but a single new botanical or zoölogical work may now describe more than that number of species new to the records of Science. Linnaeus in 1758 published the tenth edition of his 'Systema Naturae' and named about four thousand animals, and every year since 1864 the 'Zoölogical Record' has listed three or four times this number of species previously undescribed, yet now, as in Linnaeus's time, it is certain that not half of the number of species of animal organisms is yet known. The six hundred thousand, more or less, on the registers of Science to-day are certainly far less than half of the millions which actually exist.

In botany the same conditions are to be found. There are fewer known species of plants than animals by half, and they are more easily preserved and handled, while the work of collection and investigation proceeds on a scale even more extensive, yet it would be a bold statement to say that to-day half the species of plants that exist are known.

All this refers to the forms now living, without reference to the host which composes their long ancestry, extending backward toward the dawn of creation. The species have come down through the geological ages, changing in form and function to meet the varying needs of changing environment. This enumeration takes no account of the still vaster myriads of forms almost endlessly varied, which have perished utterly in the pressure of environment, leaving no trace in the line o fdescent.

It is evident that variety in life is a factor in the history of the globe, that it may be expressed in terms of number of species, but that the actual range of variation is far greater than the number of species, and that if causes are to be judged by range of effects, in the origin of species must be found the operation of world-wide forces, the cooperation of great influences, far-reaching in time and space, as broad as the surface of the globe and as enduring as its life.

The cause of this amazing variety in life, and the manner of accounting for origin of species are questions necessarily asked when attention is called to the existence of such vast numbers of species of plants and animals. In earlier chapters the theories of the origin of life have been described and proof that present living matter has descended from preexisting living matter has been outlined. It is, in fact, accepted in modern science that there has been a continuity of descent from the first living matter to that of the present time. But the form or species in which life first originated is another subject, and almost as great. Such a subject must deal with the questions as to whether life first appeared in each species of animal or plant separately, or whether it began in simple protoplasm from which have been evolved the almost numberless species known to-day.

It is quite clear that there are only two hypotheses in the field whereby it is possible so much as to suggest an explanation of the origin of species. Either all the species

of plants and animals must have been supernaturally created, or else they must have been naturally evolved. There is no third hypothesis possible; for no one can rationally suggest that species have been eternal.

It should be noticed that whichever of the two rival theories is entertained, the concern is not with any question touching the origin of life, but only with the origin of particular forms of life—that is to say, with the origin of species. The theory of descent starts from life as a 'datum' already granted. How life itself came to be, the theory of descent, as such, is not concerned to show. Therefore, in the present discussion, the existence of life is taken as a fact which does not fall within its range of debate.

The history of biology in the nineteenth century will be famous because of the discussion of these two hypotheses which attempt to account for the existence of the innumerable species of living things which inhabit the earth: the theory of creation and the theory of evolution. According to the theory of creation, all the individuals of every species existing at the present day—the tens of thousands of dogs, oak trees, amoebae, and what-not—are derived by a natural process of descent from a single individual, or from a pair of individuals—in each case precisely resembling, in all essential respects, their existing descendants—which came into existence by a process outside the ordinary course of nature, and known as Creation.

According to the rival theory—that of Descent or Organic Evolution—every species existing at the present day is derived by a natural process of descent from some other species which lived in a former period of the world's history. If from generation to generation the individuals of any existing species could be traced back, on this hypothesis, their characters would be found gradually to change, until finally a period was reached at which the differences were so considerable as to necessitate the placing of the

ancestral forms in a different species from their descendants at the present day. And in the same way if the species of any one genus could be traced back they would gradually approach one another in structure until they finally converged in a single species, differing from those now existing but standing to all in a true parental relation.

In regard to the present standing of these two theories it should be stated that the theory of descent is now generally accepted by men of science and the theory of special creation rejected. In fact no great naturalist since Agassiz has attacked the general theory, tho some have debated many of its minor details. As David Starr Jordan has said: "There is to-day no doubt in our minds of the truth, the actuality, of descent. It is not the theory of descent: it is the fact, the law, of descent, of which we talk and write. Organisms are blood-related; they are transformed, descended from one another."

At this point it will clarify some later considerations if it is emphasized that there is a great distinction to be drawn between the fact of evolution and the manner of it, or between the evidence of evolution as having taken place somehow, and the evidence of the causes which have been concerned in the process. This most important distinction is frequently disregarded by popular writers on evolution, and, therefore, in order to mark it as strongly as possible, it will be necessary to effect a complete separation between the evidence of evolution as a fact, and the evidence as to its method. In other words, not until the evidence of organic evolution as a process, which somehow or another has taken place, has been fully considered, is it advisable to consider how it has taken place, or the causes which Darwin and others have suggested as having probably been concerned in this process.

First there is to be considered, therefore, the evidences pointing to the fact of organic descent (evolution) of species of animals and plants and later there will be outlined the trend of the enormous amount of investigation

which has been and now more actively than ever is being done toward the solution of the problems concerned with the causes or the factors of evolution. In passing, it must be noted that while Darwin wrote both concerning the evidences of evolution and the manner or causes of evolution, it is not correct, as many authors assume, to regard the 'Darwinian Theory' or 'Darwinism' as synonymous with the theory of descent or evolution. Rather should the terms 'Darwinism' and Darwinian Theory' be applied to the theory of natural selection, Darwin's great explanation of the cause of the origin of species by evolution or descent.

The late Professor Cope, of Philadelphia, defines evolution in the broadest sense, including both organic and inorganic evolution, as follows: "The doctrine of evolution may be defined as the teaching which holds that creation has been and is accomplished by the agency of the energies which are intrinsic in the evolving matter, and without the interference of agencies which are external to it. It holds this to be true of the combinations and forms of inorganic nature, and of those of organic nature as well. Whether the intrinsic energies which accomplish evolution be forms of radiant or other energy only, acting inversely as the square of the distance, and without consciousness, or whether they be energies whose direction is affected by the presence of consciousness, the energy is a property of the physical basis of tridimensional matter, and is not outside of it."

But a distinction must be made between organic and inorganic evolution. Professors Jordan and Kellogg have stated this most clearly in 'Evolution and Animal Life': "Biological evolution and cosmic evolution are not the same. From the biological side a certain objection must be made to this philosophical theory of universal or cosmic evolution. In organic and inorganic evolution there is much in common, so far as conditions and results are concerned; but these likenesses belong to the realm of

analogy, not of homology. They are not true identities because not arising from like causes. The evolution of the face of the earth forces parallel changes in organic life, but the causes of change in the two cases are in no respect the same. The forces or processes by which mountains are built or continents established have no homology with the forces or processes which transformed the progeny of reptiles into mammals or birds.

"Tendencies in organic development are not mystic purposes, but actual functions of actual organs. Tendencies in inorganic nature are due to the interrelations of mass and force, whatever may be the final meanings attached to these terms or to the terms matter and energy. It is not clear that science has been really advanced through the conception of the essential unity of organic evolution and cosmic evolution. The relatively little the two groups of processes have in common has been overemphasized as compared with their fundamental differences.

"The laws which govern living matter are in a large extent peculiar to the process of living. Processes which are functions of organs cannot exist where there are no organs. The traits of protoplasm are shown only in the presence of protoplasm. For this reason we may well separate the evolution of astronomy, the evolution of dynamic geology and of physical geography, as well as the purely hypothetical evolution of chemistry, from the observed phenomena of the evolution of life.

"To regard cosmic evolution and organic evolution as identical or as phases of one process is to obscure facts by verbiage. There are essential elements in each not shared by the other—or which are at least not identical when measured in terms of human experience. It is not clear that any force whatever or any sequence of events in the evolution of life is homologous with any force or sequence in the evolution of stars and planets. The unity of forces may be a philosophical necessity. A philosophical necessity or corner in logic is unknown to science. We can recog-

nise no logical necessity until we are in possession of all the facts. No ultimate fact is yet known to science.

"For reasons indicated above the term 'evolution' is not wholly acceptable as the name of a branch of science. The term 'bionomics' is a better designation of the changing of organisms influenced through unchanging laws. It is a name broader and more definite than the term organic evolution, it is more euphonious than any phrase meaning life adaptation, it involves and suggests no theory as to the origin of the phenomena it describes."

The theory of descent of plants and animals is defined by the same authors as the "belief that organs and species as we know them are derived from other and often simpler forms by processes of divergence and adaptation. According to this theory all forms of life now existing, or that have existed on the earth, have risen from other forms of life which have previously lived in turn. All characters and attributes of species and groups have developed with changing conditions of life. The homologies among animals are the results of common descent. The differences are due to various influences, one of the leading forces among these being competition in the struggle for existence between individuals and between species, whereby those best adapted to their surroundings live and produce their kind."

This theory is now the central axis of all biological investigation in all its branches, from ethics to histology, from anthropology to bacteriology. In the light of this theory every peculiarity of structure, every character or quality of individual or species, has a meaning and a cause. It is the work of the investigator to find this meaning as well as to record the fact. "One of the noblest lessons left to the world by Darwin," says Frank Cramer, "is this, which to him amounted to a profound, almost religious conviction, that every fact in nature, no matter how insignificant, every stripe of color, every tint of flowers, the length of an orchid's nectary, unusual height in a

plant, all the infinite variety of apparently insignificant things, is full of significance. For him it was an historical record, the revelation of a cause, the lurking place of a principle." It is therefore a fundamental principle of the science of bionomics that every structure and every function of to-day finds its meaning in some condition or in some event of the past.

Darwin's own view of the doctrine of descent is clearly set forth in the following passages from the 'Origin of Species': "Authors of the highest eminence seem to be fully satisfied with the view that each species has been independently created. To my mind it accords better with what we know of the laws impressed on matter by the Creator, that the production and extinction of the past and present inhabitants of the world should have been due to secondary causes, like those determining the birth and death of the individual.

"When I view all beings not as special creations, but as the lineal descendants of some few beings which lived long before the first bed of the Cambrian system was deposited, they seem to me to become ennobled. Judging from the past, we may safely infer that not one living species will transmit its unaltered likeness to a distant futurity. And of the species now living very few will transmit progeny of any kind to a far distant futurity; for the manner in which all organic beings are grouped, shows that the greater number of species in each genus, and all the species in many genera, have left no descendants, but have become utterly extinct. We can so far take a prophetic glance into futurity as to foretell that it will be the common and widely spread species, belonging to the larger and dominant groups within each class, which will ultimately prevail and procreate new and dominant species. As all the living forms of life are the lineal descendants of those which lived long before the Cambrian epoch, we may feel certain that the ordinary succession by

generation has never once been broken, and that no cataclysm has desolated the whole world.

"It is interesting to contemplate a tangled bank, clothed with many plants of many kinds, with birds singing on the bushes, with various insects flitting about, and with worms crawling through the damp earth, and to reflect that these elaborately constructed forms, so different from each other, and dependent upon each other in so complex a manner, have all been produced by laws acting around us. There is grandeur in this view of life, with its several powers, having been originally breathed by the Creator into a few forms or into one; and that, while this planet has gone cycling on according to the fixed law of gravity, from so simple a beginning endless forms most beautiful and most wonderful have been and are being evolved."

What organic evolution does not mean is a topic which deserves some attention before discussing the evidences for evolution. President Jordan has written in 'Foot-Notes to Evolution' a strong statement concerning this, wherein he says: "Evolution is not a theory that 'man is a developed monkey.' The question of the immediate origin of man is not the central or overshadowing question of evolution. This question offers no special difficulties in theory, altho the materials for exact knowledge are in many directions incomplete. Homologies more perfect than those connecting man with the great group of monkeys could not exist. These imply the blood relationship of the human race with the great host of apes and monkeys. As to this there can be no shadow of a doubt, and, as similar homologies connect man with all members of the group of mammals, similar blood relationship must exist; and homologies less close but equally unmistakable connect all backboned animals one with another, and the lowest backboned types are closely joined to wormlike forms not usually classed as vertebrates.

"It is perfectly true that in the higher or anthropoid apes the relations with man are extremely intimate; but

man is not simply 'a developed ape.' Apes and men have diverged from the same primitive stock—apelike, manlike, but not exactly the one nor the other. No apes nor monkeys now extant could apparently have been ancestors of primitive man. None can ever 'develop' into man. As man changes and diverges, race from race, so do they. The influence of effort, the influence of surroundings, the influence of the sifting process of natural selection, each acts upon them as it acts upon man.

"The process of evolution is not progress, but better adaptation to conditions of life. As man becomes fitted for social and civic life, so does the ape become fitted for life in the tree-tops. The movement of monkeys is toward simianity, not humanity. The movement of cat life is toward felinity, that of the dog races toward caninity. Each step in evolution upward or downward, whatever it may be, carries each species or type farther from the primitive stock. These steps are never retraced. For an ape to become a man he must go back to the simple characters of the simple common type from which both have sprung. These characters are shown in the ape baby and in the human embryo in its corresponding stages, for ancestral traits lost in the adult are evident in the young. This persistence comes through the operation of the great force of cell memory which we call heredity.

"The evidence of biology points to the descent of all mammals, of all vertebrates, of all animals, of all organic beings, from a common stock. Of all the races of animals the anthropoid apes are nearest man. Their divergence from the same stock must be comparatively recent. Man is the nomadic, the apes are the arboreal, branch of the same great family.

"Evolution does not teach that all or any living forms are tending toward humanity. It does not teach, as in Bishop Wilberforce's burlesque, 'that every favorable variety of the turnip is tending to become man.' It is not true that evolutionists expect to find, as Dr. Seelye has

affirmed, 'the growth of the highest alga into a zoophyte, a phenomenon for which sharp eyes have sought, and which is not only natural but inevitable on the Darwinian hypothesis, and whose discovery would make the fame of any observer.'

"It is no wonder that a clear thinker should have rejected 'the Darwinian hypothesis' when stated in such terms as this. The line of junction in evolution is always at the bottom. It is the lowest mammals which approach the lowest reptiles; it is the lower types of plants which approach the lower types of animals; it would be the lowest Alga, to use Dr. Seelye's illustration, which would be transmutable into the lowest zoophyte; it is the unspecialized, undifferentiated type from which branches diverge in different ways. Humanity is not the 'goal of evolution,' not even that of human evolution. There will be no second creation of man, except from man's own loins. There will not be a second Anglo-Saxon race unless it has the old Anglo-Saxon blood in its veins.

"Adaptation by divergence—for the most part of slow stages—is the movement of evolution. While occasional leaps or sudden changes occur in the process, they are by no means the rule. In most cases of 'saltatory evolution' the suddenness is in appearance only. It comes from our inability to trace the intermediate stages. When an epoch-making character is acquired, as the wings of a bird or the brain of man, the process of readjustment of other characters goes on with greatly increased rapidity. But this rapidity of evolution is along the same lines as the slower processes. Radical changes from generation to generation never occur.

"We do not expect to find birds arising from a 'flying-fish in the air, whose scales are disparting into feathers.' A flying-fish is no more of the nature of a bird than any other fish is. A cow will never give birth to a horse, nor a horse to a cow. The slow operation of existing causes is the central fact of organic evolution, as it is of the evolu-

tion of mountains and valleys. Seasons change as the relations which produce them change. But midsummer never gives way to midwinter in an instant. Nor does the child in an instant become a man, tho in some periods of growth epoch-marking causes may make development more rapid. Life is conservative. The law of heredity is the expression of its conservatism. Life changes slowly, but it must constantly change, and all change is, by necessity, divergence.

"There is in Nature no single 'law of progress,' nor is progress in any group a necessity regardless of conditions. That which we call progress rests simply on the survival of the better adapted, their survival being accompanied by their reproduction. Those that live repeat themselves. The 'innate tendency toward progression' of the early evolutionists is a philosophic myth. Progress and degeneration are alike the resultants of the various forces at work from generation to generation on and within a race or species. The same forces which bring progress to a group under one set of conditions will bring degradation under another. In their essence the factors of evolution are no more laws of progress than the attraction of gravitation is. Cosmic order comes from gravitation. Organic order comes from the factors of evolution. Evolution is simply orderly change.

"Nor is evolution identical with the notion of spontaneous generation. There is no necessary connection between the one theory and the other. If there is now spontaneous generation of protoplasm, it cannot take the form of any creature we know. An organism fresh from the mint of creation would be too small for us to see with any microscope. It would be too simple for us to trace by any instrumentality now in our possession. It would contain but a few molecules, and a molecule in a drop of water is as small as an orange beside the sun. Such a race of creatures, spontaneously generated, without concessions to environment, would grow hoary with the centuries

before it came to our notice. Its descendants would have belonged for ages to the unnumbered hosts of microbes before we should be aware of its creation.

"Evolution is not a creed or a body of doctrine to be believed on authority. There is no saving grace in being an evolutionist. There are many who take this name and have no interest in finding out what it means or in making any application of its principles to the affairs of life. For one who cares not to master its ideas there is no power in the word. Evolution is not a panacea or a medicine to be applied to social or personal ills. It is simply an expression of the teaching of enlightened common sense as to the order of changes in life. If its principles are mastered, a knowledge of evolution is an aid in the conduct of life, as knowledge of gravitation is essential in the building of machinery.

"There is nothing 'occult' in the science of evolution. It is not the product of philosophic meditation or of speculative philosophy. It is based on hard facts, and with hard facts it must deal. It seems to me that it is not true that 'Evolution is a new religion, the religion of the future.' There are many definitions of religion, but evolution does not fit any of them. It is no more a religion than gravitation is.

"One may imagine that some enthusiastic follower of Newton may, for the first time, have seen the majestic order of the solar system, may have felt how futile was the old notion of guiding angels, one for each planet, to hold it up in space. He may have received his first clear vision of the simple relations of the planets, each forever falling toward the sun and toward one another, each one by the same force forever preserved from collision. Such a man might have exclaimed, 'Great is gravitation; it is the new religion, the religion of the future!' In such manner, men trained in dead traditions, once brought to a clear insight of the noble simplicity and adequacy of the theory of evolution, may have exclaimed, 'Great is evolu-

tion; it is the new religion, the religion of the future!' But evolution is religion in the same sense that every truth of the physical universe must be religion. That which is true is the truest thing in the world, and the recognition of the infinite soundness at the heart of the universe is an inseparable part of any worthy religion."

The evidences which have convinced men of science that the origin of the various species of plants and animals through descent is a fact are many and are drawn from various sources; however, no more than an outline of those facts which help best to an understanding of the doctrine can be given here. The same facts were once used in debate concerning the probabilities of the truth or untruth of the doctrine of descent, but to-day the biologist feels it unnecessary to stand as an advocate arguing for belief in evolution. As the days have long passed when the shape of the earth, or the behavior of the members of the solar system, was a fit subject for debate, so the days are now closed when the truth or falsity of the law of organic descent is a debatable thesis. That the earth is subspherical, that the planets revolve about the sun, and that species of organisms descend from other species, are now to be considered matters uncontrovertible.

Darwin wrote for a generation which had not accepted evolution, and which poured contempt on those who upheld the derivation of species from species by any natural law of descent. He did his work so well that "descent with modification" is now universally accepted as the order of nature in the organic world; and the rising generation of naturalists can hardly realize the novelty of this idea, or that their fathers considered it a scientific heresy to be condemned rather than seriously discussed.

CHAPTER X

EVIDENCES OF ORGANIC DESCENT; MORPHOLOGY AND EMBRYOLOGY

The facts of biology which admit of adequate explanation only in connection with the theory of descent are grouped by Romanes and other writers on organic evolution under the heads of morphology, embryology, classification, paleontology, distribution and domestication. In all these lines the facts are drawn together by a strong thread of unity. There are numberless similarities and correlations and surprising uniformities. The great variety of life as exhibited in the countless species of plants and animals has been referred to, and yet, great as this variety is, there are, after all, only a few types of structure among all animals and plants, some three or four or eight or ten general modes of development, and all the rest are modifications from these few types.

It is, moreover, true that all living forms are but series of modifications and extensions of one single plan of structure. All have the same ultimate substance—the mysterious semi-fluid network of protoplasm, which is, so far as is known, the physical basis of all life; and the equally mysterious nuclear substance or chromatin which in some fashion presides over all the movements of the protoplasm and is the physical basis of the phenomena of heredity. The same laws of heredity, variability and of response to outside stimulus hold in all parts of the organic world. All organisms have the same need of reproduction. All are

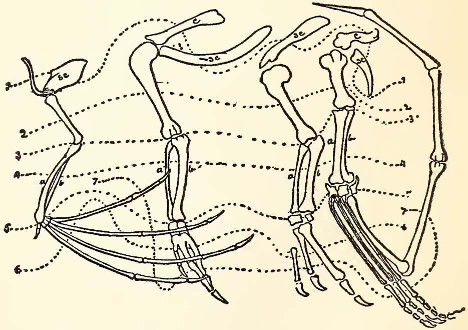
forced to make concession after concession to their surroundings, and in these concessions all progress in life consists. And at last each organism or each alliance of organisms must come to the greatest concession of all, which is called death. The unity in life, then, is not less a fact than is life's great diversity. Whatever emphasis is laid upon the diversity of life, the essential unity of all organisms must not be forgotten.

An examination of the facts in each of the lines of evidence makes it clear that the only reasonable explanation for the existence of a fundamental unity in organic life is the theory of descent—*i.e.*, that similarities are due to blood relationship and that differences come from adaptive modifications. The facts adduced from morphology, being the result of researches into the structure of adult animals and plants, lead to a preview of certain principles of adaptation, necessary for their interpretation.

First, it must be noted that some structures are not non-adaptive, that is, do not change to fit changed habits or conditions of life. Such structures or organs are most often found internally. For illustration: a change in the locomotive habit of a bird from that of flying to that of an ostrich is associated with an adaptive modification of locomotor structures, legs and wings, but not in any striking way is there change in the internal organs. Internal organs may persist unchanged and hence they offer good guides to classification. On the other hand, external structures are likely to undergo adaptation when habits or conditions of life change. Hence, as Jordan has said, "the inside of an animal tells the real history of its ancestry; the outside tells us only where its ancestors have been."

In the second place, it must be noted that adaptations to similar conditions may result in superficial resemblances. For example, there is a superficial resemblance between the wing of an insect and the wing of a bird—both adaptations to an aerial environment; between the heart of an insect and the heart of a vertebrate animal—both adaptations for

pumping blood; between the fin of a fish and the paddle of a whale—both adaptive swimming organs, yet the resemblance in these cases does not go deeper than the surface—it is one of function only. All such cases of resemblance in function but not in detailed plan of structure are called 'analogies,' and mean nothing more than similarity of environment. Turning to more fundamental resemblances, such as the wing of a bat and the wing of a bird, careful study shows detailed internal as well as external similarities of structure. Such cases are 'homologies.'



Bat. Bird. Archæopteryx. Pterodactyl.
Fig. 15 —Homologies in Wings. (LeConte.)

On the one hand, then, are found structures which are perfectly analogous and yet in no way homologous: totally different structures are modified to perform the same functions. On the other hand are found structures which are perfectly homologous and yet in no way analogous: the structural elements remain, but are profoundly modified to perform totally different functions. Homology thus means identity of structure which is the result of identity

of parentage. It is the stamp of heredity. It means blood relationship. These principles of homology are essential to a correct interpretation of the facts of morphology.

The most striking fact of similar structure among plants and among animals is the existence of a common general plan in any group. Since backboned animals are best known to most readers, they may be taken as an illustration. "All vertebrate animals, and none other," says Le Conte, "have an internal jointed skeleton worked by muscles on the outside. The relation of skeleton and muscle in arthropods is exactly the reverse.

"In all vertebrates, and in none other, the axis of this skeleton is a jointed backbone (vertebral column) inclosing and protecting the nervous centers (cerebro-spinal axis). These, therefore, may well be called backboned animals.

"All vertebrates, and none other, have a number of their anterior vertebral joints enlarged and consolidated into a box to form the skull, in order to inclose and protect a similar enlargement of the nervous center, viz., the brain; and also usually, but not always, a number of posterior joints, enlarged and consolidated to form the pelvis, to serve as a firm support to the hind-limbs.

"All vertebrates, and none other, have two cavities, inclosed and protected by the skeleton, viz., the neural cavity above, and the visceral or body cavity below, the vertebral column.

"All vertebrates, with few exceptions, and no other animals, have two and only two pair of limbs. The exceptions are of two kinds, viz.: (a) some lowest fishes, amphioxus and lampreys, which probably represent the vertebrate condition before limbs were acquired; and (b) degenerate forms like snakes and some lizards, which have lost their limbs by disuse.

"So much concerns the general plan of skeletal structures and is strongly suggestive of—in fact it is inexplicable without—common origin. But much more remains which is not only suggestive, but demonstrative of

such origin. By extensive comparison in the taxonomic and ontogenic series, the whole vertebrate structure in all its details in different animals may be shown to be modifications one of another. Sometimes a piece is enlarged, sometimes diminished, or even becomes obsolete; sometimes several pieces are consolidated into one; but, in spite of all these obscurations, corresponding parts usually may be made out."

These remarkable similarities in the common general

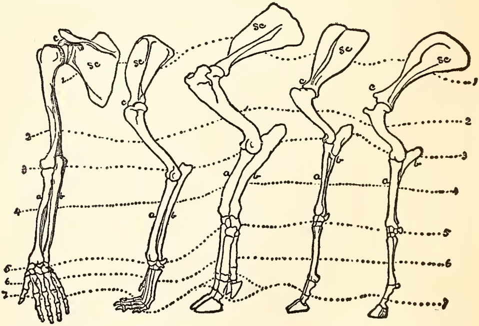
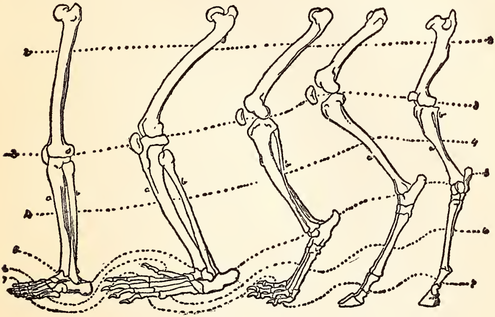


Fig. 16 —Homologies in Forehinds. (LeConte.)

plan alone are convincing evidences of descent, but attention may be called to a like similarity extending to the details of structure. For example: the wings of a bat (a mammal), a bird and a fossil flying reptile all show the same bones adaptively modified; a series of either fore or hind limbs of a mammal with one toe (horse), two toes (sheep), four toes (hog) and five toes (dog) exhibit a remarkable series of homologies pointing to a five-toed ancestor, and any other series of organs of vertebrates

would give the same evidence of fundamental resemblances (homologies). For such a series of facts the reader must be referred to special books like Wiedersheim's 'Comparative Anatomy of the Vertebrates,' Romanes's 'Darwin and After Darwin,' and Le Conte's 'Evolution.'

The existence of great similarities in vertebrate structure is not always fully recognised. To the superficial observer the bodies of animals of different classes seem to differ fundamentally in plan, to be entirely different



Man. Gorilla. Dog. Sheep. Horse.

Fig. 17 —Homologies in Hind Limbs.. Romanes.)

machines, made each for its own purposes, at once, out of hand. Extensive comparison, on the contrary, shows them to be the same, altho the essential identity is obscured by adaptive modifications. The simplest, in fact the only scientific, explanation of the phenomena of vertebrate structure is the idea of a primal vertebrate, modified more and more through successive generations by the necessities of different modes of life.

See, then, the difference between man's mode of work-

ing and Nature's. A man having made a steam-engine, and desiring to use it for a different purpose from that for which it was first designed and used, will nearly always be compelled to add new parts not contemplated in the original machine. Nature rarely makes new parts—never, if she can avoid it—but, on the contrary, adapts an old part to the new function. It is as if Nature were not free to use any and every device to accomplish her end, but were conditioned by her own plans of structure; as, indeed, she must be according to the derivation theory. Thus, in the fin of a fish, the fore-paw of a reptile or a mammal, the wing of a bird, and the arm and hand of a man, is found the same part, variously modified for many purposes.

Another striking class of the facts of morphology which admit of scientific explanation only along the line of homology are the thousands of cases of rudimentary or vestigial structures to be found. Throughout both the animal and vegetable kingdoms dwarfed and useless representatives of organs are constantly met with, which in other and allied kinds of animals and plants are of large size and functional utility. Thus, for instance, the unborn whale has rudimentary teeth, which are never destined to cut the gums; and throughout its life this animal retains, in a similarly rudimentary condition, a number of organs which never could have been of use to any kind of creature save a terrestrial quadruped.

Other well-known examples among vertebrates are: Vestiges of hind limbs in certain snakes, reduced wings in the Apteryx and ostriches, rudiments of eyes in cave fishes, hind limbs beneath the skin of whales, the vermiform appendix in man, as well as useless muscles to move the ears and the skin, and also a very much reduced hairy covering over the surface of the body. Wiedersheim has recorded more than one hundred and eighty such structural reminiscences in man.

Now, rudimentary organs of this kind are of such

Fig. 18 —Homologies of Foot and Hand Bones.
1., man; 2., gorilla; 3., orang-utan; 4., dog; 5., sea lion; 6., dolphin; 7, bat; 8, mole; 9, ornithorhynchus. (Haeckel.)

frequent occurrence, that almost every species of organism presents one or more of them—usually, indeed, a considerable number. How, then, are they to be accounted for? Of course the theory of descent with adaptive modification has a simple answer to supply—namely, that when, from changed conditions of life, an organ which was previously useful becomes useless, it will be suffered to dwindle away

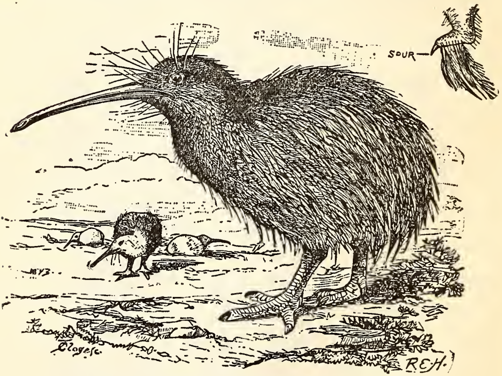


Fig. 19 —Vestigial Structures in Apteryx.
External wing is drawn to scale in the upper part of the cut.

in successive generations, under the influence of certain natural causes.

On the other hand, the theory of special creation can only maintain that these rudiments are formed for the sake of adhering to an ideal type.

"Now, here again the former theory appears to be triumphant over the latter," says Romanes, "for, without waiting to dispute the wisdom of making dwarfed and useless structures merely for the whimsical motive assigned,

surely if such a method were adopted in so many cases, we should expect that in consistency it would be adopted in all cases. This reasonable expectation, however, is far from being realized. In numberless cases, such as that of the fore-limbs of serpents, no vestige of a rudiment is present. But the vacillating policy in the matter of rudiments does not end here; for it is shown in a still more aggravated form where within the limits of the same natural group of organisms a rudiment is sometimes present and sometimes absent. For instance, altho in nearly all the numerous species of snakes there are no vestiges of limbs, in the Python we find very tiny rudiments of the hind-limbs. Now, is it a worthy conception of Deity that, while neglecting to maintain his unity of ideal in the case of nearly all the numerous species of snakes, he should have added a tiny rudiment in the case of the Python—and even in that case should have maintained his ideal very inefficiently, inasmuch as only two limbs, instead of four, are represented?"

Convincing as are the evidences of descent recorded in the structure of plants and animals, these evidences have been in the past thirty years somewhat overshadowed by the far more surprising evidences of descent discovered in the development of plant and animal embryos. A dozen volumes would be necessary to present the mass of embryological evidence, but a few salient facts will illustrate the kind of evidence to be deduced from embryology.

Most remarkable of all the principles which have been discovered by embryologists is the 'Recapitulation Doctrine,' which, briefly stated, is that individual development (ontogeny) recapitulates ancestral history (phylogeny). Illustrations quoted from the works of Romanes and Le Conte will make this principle clear. "It is an observable fact," says Romanes, "that there is often a close correspondence between developmental changes as revealed by any chronological series of fossils which may happen

to have been preserved, and developmental changes which may be observed during the life-history of now existing individuals belonging to the same group of animals. For

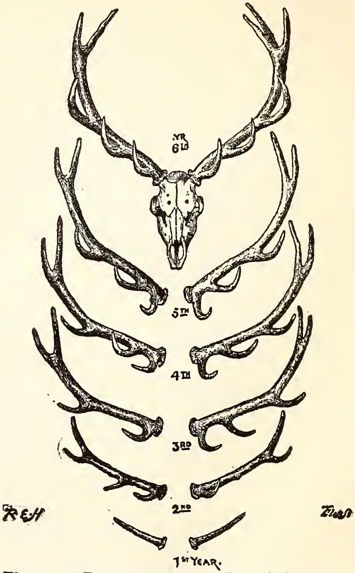


Fig. 20 —Development of Stags' Antlers.
Horns of fossil deer show in species the same increase of complexity that present species shows in lifetime.

instance, the successive development of prongs in the horns of deer-like animals, which is so clearly shown in the geological history of this tribe, is closely reproduced

in the life-history of existing deer. Or, in other words, the antlers of an existing deer furnish in their development a kind of 'résumé,' or recapitulation, of the successive phases whereby the primitive horn was gradually superseded by horns presenting a greater and greater number of prongs in successive species of extinct deer.

"Now, it must be obvious that such a recapitulation in the life-history of an existing animal of developmental changes successively distinctive of sundry allied, tho now extinct species, speaks strongly in favor of evolution. For as it is of the essence of this theory that new forms arise from older forms by way of hereditary descent, we should antecedently expect, if the theory is true, that the phases of development presented by the individual organism would follow, in their main outlines, those phases of development through which their long line of ancestors had passed. The only alternative view is that as species of deer, for instance, were separately created, additional prongs were successively added to their antlers; and yet that, in order to be so added to successive species, every individual deer belonging to later species was required to repeat in his own lifetime the process of successive additions which had previously taken place in a remote series of extinct species. Now I do not deny that this view is a possible view; but I do deny that it is a probable one. According to the evolutionary interpretation of such facts, we can see a very good reason why the life-history of the individual is thus a condensed 'résumé' of the life-history of its ancestral species. But according to the opposite view no reason can be assigned why such should be the case."

"It is well known," likewise comments Le Conte, "that the embryo or larva of a frog or toad, when first hatched, is a legless, tail-swimming, water-breathing, gill-breathing animal. It is essentially a fish, and would be so classed if it remained in this condition. The fish retains permanently this form, but the frog passes on. Next, it forms first one pair and then another pair of legs; and mean-

while it begins to breathe also by lungs. At this stage it breathes equally by lungs and by gills—*i.e.,* both air and water. Now, the lower forms of amphibians, such as siredon, menobranchus, siren, etc., retain permanently this form, and are therefore called 'perennibranchs,' but the frog still passes on. Then the gills gradually dry up, as the lungs develop, and they now breathe wholly by lungs, but still retain the tail. Now this is the permanent, mature condition of many amphibians, such as the triton, the salamander, etc., which are therefore called 'caducibranchs,' but the frog still passes on. Finally, it loses the tail, or rather its tail is absorbed and its material used in further development, and it becomes a perfect frog, the highest order (anoura) of this class.

"Thus, then, in ontogeny the fish goes no further than the fish stages. The perennibranch passes through the fish stage to the perennibranch amphibian. The caducibranch takes first the fish-form, then the perennibranch-form, and finally the caducibranch-form, but goes no further. Last, the anoura takes first the fish-form, then that of the perennibranch, then that of the caducibranch, and finally becomes anoura. Now, this is undoubtedly the order of succession of forms in geological times—*i.e.*, in the phylogenic series. Fishes first appeared in the Devonian and Upper Silurian in very reptilian or rather amphibian forms. Then in the Carboniferous, fishes still continuing, there appeared the lowest—*i.e.*, most fish-like forms of amphibians. These were undoubtedly perennibranchs. In the Permian and Triassic higher forms appeared, which were certainly caducibranch. Finally, only in the Tertiary, so far as we yet know, do the highest form (anoura) appear. The general similarity of the three series is complete.

"It is a curious and most significant fact that the successive stages of the development of the individual in the higher forms of any group (ontogenic series) resemble the stages of increasing complexity of differentiated structure in ascending the animal scale in that group (taxo-

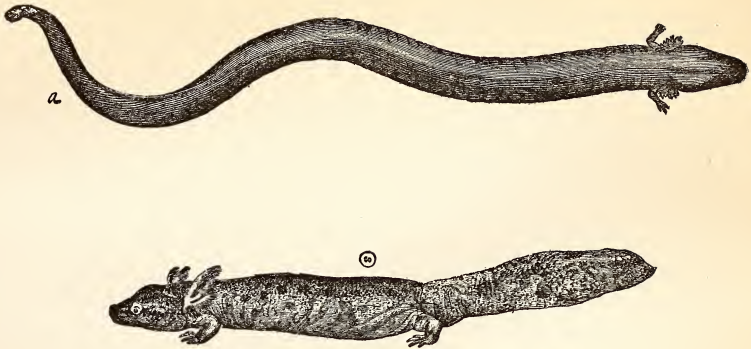


Fig. 21 —Siren Perennibranchs. (Mivart.)
Upper figure, the siren; lower, the 'Menobranchus.'

nomic series), and especially the forms and structure of animals of that group in successive geological epochs (phylogenic series). In other words, the individual higher animal in embryonic development passes through temporary stages, which are similar in many respects to permanent or mature conditions in some of the lower forms in the same group.

"Surely this fact is wholly inexplicable except by the theory of derivation or evolution. The embryo of a higher animal of any group passes now through stages represented by lower forms, because in its evolution (phylogeny) its ancestors did actually have these forms. From this point of view the ontogenic series (individual history) is a brief recapitulation, as it were, from memory, of the main points of the philogenic series, or family history. We say brief recapitulation of the main points, because many minor points are dropped out. Even some main points of the earliest stages of the family history may be dropped out of this sort of inherited memory.

"This resemblance between the three series must not, however, be exaggerated. Not only are many steps of phylogeny, especially in its early stages, dropped out in the ontogeny, but, of course, many adaptive modifications for the peculiar conditions of embryonic life are added. But it is remarkable how even these—for example, the umbilical cord and placenta of the mammalian embryo—are often only modifications of egg-organs of lower animals, and not wholly new additions. It is the similarity in spite of adaptive modifications that shows the family history."

But even these recapitulations are not so convincing as are those of many internal structures which are not now of any possible use. In the fishes, the lowest class of vertebrates, gills are the organs of breathing. Water taken into the mouth is ejected from the throat through the gill-slits, which are lined with delicate vascular membranes. Blood circulating through these membranes ab-

sorbs oxygen from the water and gives off carbon dioxide gas. Thus in the fishes the gills play the part performed by lungs in higher forms, and are essential organs throughout life. Passing up the scale of animal life, amphibian embryos develop gill-slits and they are present and functionally active for a few days in the early life of certain tadpoles. In all amphibians the slits close soon and the fully developed frogs and salamanders do not use them for breathing. Certain amphibians have gills throughout life, but they are not the gills corresponding to those of fishes.

Now, in interpreting these facts, it should be noted that the embryos of the higher classes, reptiles, birds and mammals, never have access to water and yet in every species whose development is known gill-slits are present in the embryos. For example, in a chick of three to five days' incubation there are four slits on the side of the neck. Likewise there are several gill-slits in human embryos of three to five weeks' development. In all reptiles, birds and mammals the gill-slits, however, are temporary; they serve no function and close long before hatching or birth. The only interpretation which appeals to the biologist as reasonable is that gill-slits in the higher vertebrates are reminiscences of ancestral history and, originally fish organs, they appear regularly in the fish-like stage of every embryo of higher forms which in their development pass through stages comparing in a general way to the adults of lower forms.

There are dozens and dozens of similar cases known to occur in the embryology of vertebrates. The notochord, which is the dorsal stiffening axis in the lowest vertebrate (amphioxus), appears in the embryos of all higher forms. In them it is purely temporary and disappears as the backbone is developed around it. The lungs of amphibia and higher forms develop in the embryo identically with the air-bladder of fishes.

In the embryonic development of man and other mammals three pairs of kidneys are formed, only one remain-

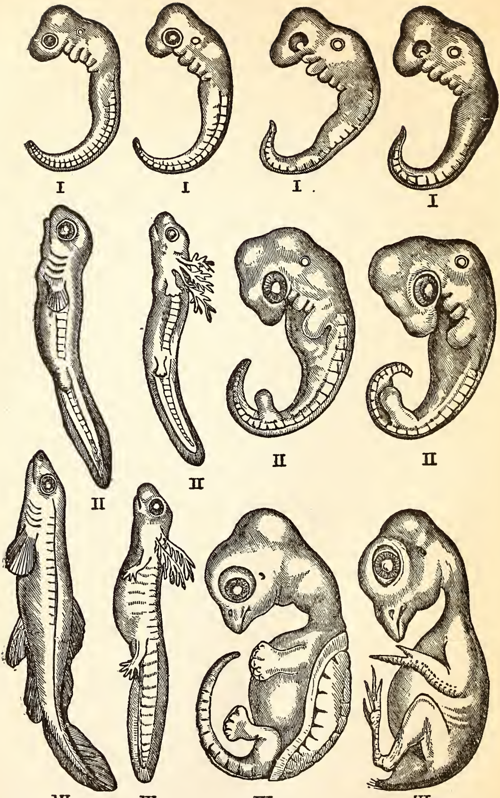


Fig. 22 —EMBRYONIC STAGES. Fish, Salamander, Tortoise, Chick.

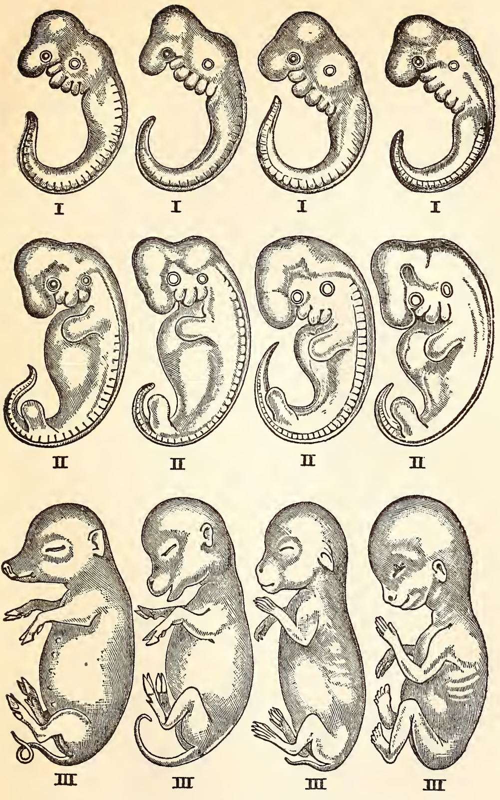


Fig. 23 —Embryonic Stages. Hog, Calf, Rabbit, Man.

ing at birth. The first kidneys (pronephros) develop in the stage when gills and other structures correspond to a fish-embryo stage, and in some of the lowest fishes this pair becomes the permanent kidneys. The second kidneys (mesonephros) correspond to an amphibian-reptilian stage, and this pair persists throughout life in the amphibia, in the embryos of which the first kidneys are temporarily present. The third kidneys (metanephros) succeed the first and second in mammalian development and remain throughout life. In the higher forms the first and second kidneys are absolutely useless. The only reasonable explanation of this fact is that the appearance of the first kidneys in amphibian embryos and of the first and second in mammalian embryos is due to this repetition or recapitulation of ancestral history.

If space permitted it would be easy to present abundance of additional evidence to the same effect from the development of the skeleton, the skull, the brain, the sense-organs, and, in short, of every constituent part of the vertebrate organization. Even without any anatomical dissection, the similarity of all vertebrate embryos at comparable stages of development admits of being strikingly shown, if the embryos are merely placed one beside the other. Here, for instance, are the embryos of a fish, a salamander, a tortoise, a bird, and four different mammals. In each case three comparable stages of development are represented. Now if the series is read horizontally, it can be seen that there is very little difference between the eight animals at the earliest of the three stages represented—all having fish-like tails, gill-slits, and so on. In the next stage further differentiation has taken place, but it will be observed that the limbs are still so rudimentary that even in the case of man they are considerably shorter than the tail. But in the third stage the distinctive characters are well marked.

So far examples have been drawn entirely from the vertebrate animals; it should be pointed out, however, that

there is a repetition of just the same kind of evidence in all the other groups of animals, and as well in the plant kingdom. When all this mass of evidence is taken together, it is not to be wondered at that the science of comparative embryology should be considered as the principal witness to the theory of descent.

But why should ontogeny repeat the steps of phylogeny? Professor Le Conte replies that "the general answer is doubtless to be found in the law of heredity—that wonderful law, so characteristic of living things. We have compared it to a brief recapitulation from memory—the minor points, especially if they be also early, dropping out. But can we not explain it further? It is probable that we find a more special explanation in 'the law of acceleration,' first brought forward by Prof. Cope. By the law of heredity each generation repeats the form and structure of the previous, and in the order in which they successively appeared. But there is a tendency for each successively appearing character to appear a little earlier in each successive generation; and by this means time is left over for the introduction of still higher new characters. Thus, characters which were once adult are pushed back to the young, and then still back to the embryo, and thus place and time are made for each generation to push on still higher. The law of acceleration is a sort of young-Americanism in the animal kingdom. If our boys acquire knowledge and character similar to that of adults of a few generations back, they will have time while still young and plastic to press forward to still higher planes."

These similarities or homologies of embryology appeal to the thinker, as has been said, as explainable only on the theory of descent. Agassiz, however, held an opposing view. His statements on this point are classical in biological literature. He says: "If we now pass to the highest type of the Animal Kingdom, the Vertebrates, there is no lack of evidence to show the identity in their mode of development, as well as the striking resemblance

of the young in their earliest stages of growth. The young Fish, the young Reptile, the young Bird, the young Mammal, resemble one another to an astonishing degree, while they have not one feature in their mode of growth which recalls either the Articulate, the Mollusk, or the Radiate. It is, therefore, not true, tho so often stated, that in their development the higher animals pass successively through the condition of all the lower ones; while it is emphatically true that in each of the four great branches of the Animal Kingdom there is a common mode of development. It is equally true that in certain features the higher classes of each branch in their younger condition recall the characteristic features of the lower ones, tho each class has its own structural character, and early diverges from the common starting-point.

"Indeed, modern Embryology leads at once to the consideration of the most occult problem, as to the origin of animals, suggested by these comparisons. What do these resemblances mean, from some of which we shrink as unnatural and even revolting? If we put a material interpretation upon them, and believe that even Man himself has been gradually developed out of a Fish, they are repugnant to our better nature. But looked at in their intellectual significance, they truly reveal the unity of the organic conception of which Man himself is a part, and mark not only the incipient steps in its manifestation, but also, with equal distinctness, every phase in its gradual realization. They mean that when the first Fish was called into existence, the Vertebrate type existed as a whole in the creative thought, and the first expression of it embraced potentially all the organic elements of that type, up to Man himself. To me the fact that the embryonic form of the highest Vertebrate recalls in its earlier stage the first representatives of its type in geological times and its lowest representatives at the present day, speaks only of an ideal relation, existing not in the things themselves, but in the mind that made them.

"It is true that the naturalist is sometimes startled at these transient resemblances of the young among the higher animals in one type to the adult condition of the lower animals in the same type; but it is also true that he finds each one of the primary divisions of the Animal Kingdom bound to its own norm of development, which is absolutely distinct from that of all the others; it is also true, that, while he perceives correspondences between the early phases of the higher animals and the mature state of the lower ones, he never sees any one of them diverge in the slightest dgree from its own structural character—never sees the lower rise by a shade beyond the level which is permanent for the group to which it belongs—never sees the higher ones stop short of their final aim, either in the mode or the extent of their transformation.

"I cannot repeat too emphatically, that there is not a single fact in Embryology to justify the assumption that the laws of development, now known to be so precise and definite for every animal, have ever been less so, or have ever been allowed to run into each other. The philosopher's stone is no more to be found in the organic than the inorganic world; and we shall seek as vainly to transform the lower animal types into the higher ones by any of our theories, as did the alchemists of old to change the baser metals into gold."

Thus did Agassiz reject the theory of descent in the face of the most overwhelming evidence. His view that similarity of development is simply an expression of type in creative thought appeals to scientists to-day as absurd. Agassiz was the last prominent naturalist who could believe that such things as gill-slits were put into embryos of higher forms in order to adhere to an ideal plan "in the mind that made them."

The paragraphs quoted above from Agassiz suggest that it may not be known what hidden reasons there may have been for the creation of animals with such remark-

able similarities in development or adult structure. But as Romanes has pointed out, a man "may quite legitimately say, Assuming that the theory of special creation is true, it is not for us to anticipate the form or method of the process. But where the question is as to whether or not the theory is true, it becomes a mere begging of this question to take refuge in the argument from ignorance, or to represent in effect that there is no question to be discussed. And if, when the form or method is investigated, it be found everywhere charged with evidence in favor of the theory of descent, the case becomes the same as that of a supposed revelation, which has been discredited by finding that all available evidence points to a natural growth.

"In short, the argument from ignorance is in any case available only as a negative foil against destructive criticism. In no case has it any positive value or value of a constructive kind. Therefore, if a theory on any subject is destitute of positive evidence, while some alternative theory is in possession of such evidence, the argument from ignorance can be of no logical use to the former, even tho it may be of such use to the latter. For it is only the possession of positive evidence which can furnish a logical justification of the argument from ignorance. In the absence of such evidence even the negative value of the argument disappears and it then implies nothing more than the gratuitous assumption of a theory."

CHAPTER XI

EVIDENCES OF ORGANIC EVOLUTION; CLASSIFICATION, PALEONTOLOGY, DISTRIBUTION, DOMESTICATION

If a child in the kindergarten be given an assortment of cards of various colors and shapes and a number of boxes into which to put them, it becomes evident that the natural tendency is to group together the cards according to their striking resemblances, for most children probably of color. This is simply an elementary exercise in classification and in fundamentals is parallel with the accepted grouping of plants and animals on the basis of resemblances. Many authors have discussed the bearing of classification on the theory of descent, and among the best is the popular statement of the case by Romanes.

"It is a matter of observable fact," he remarks, "that different forms of plants and animals present among themselves more or less pronounced resemblances. From the earliest times, therefore, it has been the aim of philosophical naturalists to classify plants and animals in accordance with these resemblances. Of course the earliest attempts at such classification were extremely crude. The oldest of these attempts with which we are acquainted—namely, that which is presented in the books of Genesis and Leviticus—arranges the whole vegetable kingdom in three simple divisions of Grass, Herbs and Trees, while the animal kingdom is arranged with almost equal simplicity with reference first to habitats in water, earth or air and next as to modes of progression. These, of course,

were what may be termed common-sense classifications, having reference merely to external appearances and habits of life.

"But when Aristotle laboriously investigated the comparative anatomy of animals, he could not fail to perceive that their entire structures had to be taken into account in order to classify them scientifically and also that for this purpose the internal parts were of quite as much importance as the external. Indeed, he perceived that they were of greatly more importance in this respect, inasmuch as they presented so many more points for comparison, and in the result he furnished an astonishingly comprehensive as well as an astonishingly accurate classification of the larger groups of the animal kingdom. On the other hand, classification of the vegetable kingdom continued pretty much as it had been left by the book of Genesis—all plants being divided into three groups, Herbs, Shrubs and Trees. Nor was this primitive state of matters improved upon till the sixteenth century, when Gesner, and still more Cesalpino, laid the foundations of systematic botany.

"But the more that naturalists prosecuted their studies on the anatomy of plants and animals, the more enormously complex did they find the problem of classification become. Therefore they began by forming what are called artificial systems in contradistinction to natural systems. An artificial system of classification is a system based on the more or less arbitrary selection of some one part or set of parts, while a natural classification is one that is based upon a complete knowledge of all the structures of all the organisms which are classified.

"Thus the object of classification has been that of arranging organisms in accordance with their natural affinities, by comparing organism with organism, for the purpose of ascertaining which of the constituent organs are of the most invariable occurrence and therefore of the most typical signification. A porpoise, for instance, has a large number of teeth, and in this feature resembles most fish,

while it differs from all mammals. But it also gives suck to its young. Now, looking to these two features alone, should we say that a porpoise ought to be classed as a fish or as a mammal? Assuredly as a mammal, because the number of teeth is a very variable feature both in fish and mammals, whereas the giving of suck is an invariable feature among mammals and occurs nowhere else in the animal kingdom.

"This, of course, is chosen as a very simple illustration. Were all cases as obvious, there would be but little distinction between natural and artificial systems of classification. But it is because the lines of natural affinity are, as it were, so interwoven throughout the organic world, and because there is, in consequence, so much difficulty in following them that artificial systems have to be made in the first instance as feelers toward eventual discovery of the natural system. In other words, while forming their artificial systems of classification, it has always been the aim of naturalists—whether consciously or unconsciously—to admit as the bases of their systems those characters which, in the then state of their knowledge, seemed most calculated to play an important part in the eventual construction of the natural system.

"If we were dealing with the history of classification, it would here be interesting to note how the course of it has been marked by gradual change in the principles which naturalists adopted as guides to the selection of characters on which to found their attempts at a natural classification. Some of these changes, indeed, I shall have to mention later on, but at present what has to be specially noted is that through all these changes of theory or principle and through all the ever-advancing construction of their taxonomic science naturalists themselves were unable to give any intelligible reason for the faith that was in them or the faith that over and above the artificial classifications which were made for the mere purpose of cataloguing the living library of organic nature, there was deeply hidden

in nature itself a truly natural classification, for the eventual discovery of which artificial systems might prove to be of more or less assistance.

"Linnæus, for example, expressly says, 'You ask me for the characters of the natural orders; I confess that I cannot give them.' Yet he maintains that, altho he cannot define the characters, he knows, by a sort of naturalist's instinct, what in a general way will subsequently be found to be the organs of most importance in the eventual grouping of plants under a natural system. 'I will not give my reasons for the distribution of the natural orders which I have published,' he said; 'you, or some other person, after twenty or after fifty years, will discover them and see that I was right.' Thus we perceive that in forming their provisional or artificial classifications, naturalists have been guided by an instinctive belief in some general principle of natural affinity, the character of which they have not been able to define, and that the structures which they selected as the bases of their classifications when these were consciously artificial were selected because it seemed that they were the structures most likely to prove of use in subsequent attempts at working out the natural system.

"This general principle of natural affinity, of which all naturalists have seen more or less well-marked evidence in organic nature, and after which they have all been feeling, has sometimes been regarded as natural, but more often as supernatural. Those who regarded it as supernatural took it to consist in a divine ideal of creation according to types, so that the structural affinities of organisms were to them expressions of an archetypal plan, which might be revealed in its entirety when all organisms on the face of the earth should have been examined. Those, on the other hand, who regarded the general principle of affinity as depending on some natural causes, for the most part concluded that these must have been utilitarian causes; or, in other words, that the fundamental affinities of structure must have depended upon fundamental

requirements of function. According to this view, the natural classification would eventually be found to stand upon a basis of physiology.

"Therefore all the systems of classification up to the earlier part of the present century went upon the apparent axiom that characters which are of most importance to the organisms presenting them must be characters most indicative of natural affinities. But the truth of the matter was eventually found to be otherwise. For it was eventually found that there is absolutely no correlation between these two things; that, therefore, it is a mere chance whether or not organs which are of importance to organisms are likewise of importance as guides to classification, and, in point of fact, that the general tendency in this matter is toward an inverse instead of a direct proportion. More often than not the greater the value of a structure for the purpose of indicating natural affinities, the less is its value to the creatures presenting it.

"Enough has now been said to show three things. First, that long before the theory of descent was entertained by naturalists, naturalists perceived the fact of natural affinities and did their best to construct a natural system of classification for the purpose of expressing such affinities. Second, that naturalists had a kind of instinctive belief in some one principle running through the whole organic world, which thus served to bind together organisms in groups subordinate to groups—that is, into species, genera, orders, families, classes, sub-kingdoms and kingdoms. Third, that they were not able to give any very intelligible reason for this faith that was in them; sometimes supposing the principle in question to be that of a supernatural plan of organization, sometimes regarding it as dependent on conditions of physiology and sometimes not attempting to account for it at all.

"Of course it is obvious that the theory of descent furnishes the explanation which is required. For it is now evident to evolutionists that, altho these older naturalists

did not know what they were doing when they were tracing these lines of natural affinity, and thus helping to construct a natural classification—I say it is now evident to evolutionists that these naturalists were simply tracing the lines of generic relationship. The great principle pervading organic nature, which was seen so mysteriously to bind the whole creation together as in a nexus of organic affinity, is now easily understood as nothing more or less than the principle of Heredity."

Darwin first called attention to this line of evidence for evolution in the following words: "Naturalists try to arrange the species, genera and families in each class on what is called the Natural System. But what is meant by this system? Some authors look at it merely as a scheme for arranging together those living objects which are most alike and for separating those which are most unlike or as an artificial method of enunciating, as briefly as possible, general propositions—that is, by one sentence to give the characters common, for instance, to all mammals, by another those common to all carnivora, by another those common to the dog-genus, and then, by adding a single sentence, a full description is given of each kind of dog. The ingenuity and utility of this system are indisputable. But many naturalists think that something more is meant by the Natural System; they believe that it reveals the plan of the Creator, but unless it be specified whether order in time or space, or both, or what else is meant by the plan of the Creator, it seems to me that nothing is thus added to our knowledge. Expressions such as that famous one by Linnæus, which we often meet with in a more or less concealed form, namely, that the characters do not make the genus, but that the genus gives the characters, seem to imply that some deeper bond is included in our classifications than mere resemblance. I believe that this is the case and that community of descent—the one known cause of close similarity in organic beings—is the bond,

which tho observed by various degrees of modification, is partially revealed to us by our classifications."

Before the days of Darwin naturalists had classified plants and animals on a tree-like plan and had rejected the old ladder series of early systematists. The tree system is the one which all naturalists regard as the true one. "According to this system," Romanes points out, "a short trunk may be taken to represent the lowest organisms which cannot properly be termed either plants or animals. This short trunk soon separates into two large trunks, one of which represents the vegetable and the other the animal kingdom. Each of these trunks then gives off large branches signifying classes, and these give off smaller but more numerous branches, signifying families, which ramify again into orders, genera and finally into the leaves, which may be taken to represent species. Now, in such a representative tree of life, the height of any branch from the ground may be taken to indicate the grade of organization which the leaves, or species, present; so that, if we picture to ourselves such a tree, we may understand that while there is a general advance of organization from below upward, there are many deviations in this respect. Sometimes leaves growing on the same branch are growing at a different level—especially, of course, if the branch be a large one, corresponding to a class or sub-kingdom. And sometimes leaves growing on different branches are growing at the same level; that is to say, altho they represent species belonging to widely divergent families, orders or even classes, it cannot be said that the one species is more highly organized than the other.

"Now, this tree-like arrangement of species in nature is an arrangement for which Darwin is not responsible. For, as we have seen, the detecting of it has been due to the progressive work of naturalists for centuries past, and even when it was detected, at about the commencement of the present century, naturalists were confessedly unable to explain the reason of it or what was the underlying

principle that they were engaged in tracing when they proceeded ever more and more accurately to define these ramifications of natural affinity. But now we can clearly perceive that this underlying principle was none other than Heredity as expressed in family likeness—likeness, therefore, growing progressively more unlike with remoteness of ancestral relationship.

"First of all, and from the most general point of view, it is obvious that the tree-like system of classification, which Darwin found already and empirically worked out by the labors of his predecessors, is as suggestive as anything could well be of the fact of genetic relationship. For this is the form that every tabulation of family pedigree must assume, and therefore the mere fact that a scientific tabulation of natural affinities was eventually found to take the form of a tree is in itself highly suggestive of the inference that such a tabulation represents a family tree. If all species were separately created, there can be no assignable reason why the ideas of earlier naturalists touching the form which a natural classification would eventually assume should not have represented the truth—why, for example, it should not have assumed the form of a ladder (as was anticipated in the seventeenth century), or of a map (as was anticipated in the eighteenth), or, again, of a number of wholly unrelated lines, circles, etc. (as certain speculative writers of the nineteenth century have imagined). But, on the other hand, if all species were separately and independently created, it becomes virtually incredible that we should everywhere observe this progressive arborescence of characters common to larger groups into more and more numerous and more and more delicate ramifications of characters distinctive only of smaller and smaller groups. A man would be deemed insane if he were to attribute the origin of every branch and every twig of a real tree to a separate act of special creation, and altho we have not been able to witness the growth of what we may term in a new sense the Tree of

Life, the structural relations which are now apparent between its innumerable ramifications bear quite as strong a testimony to the fact of their having been due to an organic growth as is the testimony furnished by the branches of an actual tree."

Summarizing, it is established that "all the general principles and particular facts appertaining to the natural classification of plants and animals are precisely what they ought to be according to the theory of genetic descent, while no one of them is such as might be—and, indeed, used to be—expected upon the theory of special creation.

"First of all we must take note that the classification of plants and animals in groups subordinate to groups is not merely arbitrary or undertaken only for a matter of convenience and nomenclature—such, for instance, as the classification of stars in constellations. On the contrary, the classification of a naturalist differs from that of an astronomer, in that the objects which he has to classify present structural resemblances and structural differences in numberless degrees, and it is the object of his classification to present a tabular statement of these facts. Now, long before the theory of evolution was entertained, naturalists became fully aware that these facts of structural resemblances running through groups subordinate to groups were really facts of nature and not merely poetic imaginations of the mind. No one could dissect a number of fishes without perceiving that they were all constructed on one anatomical pattern which differed considerably from the equally uniform pattern on which all mammals were constructed, even altho some mammals bore an extraordinary resemblance to fish in external form and habits of life. And similarly with all the smaller divisions of the animal and vegetable kingdoms.

"Everywhere investigation revealed the bonds of close structural resemblances between species of the same genus, resemblance less close between genera of the same family, resemblance still less close between families of the

same order, resemblance yet more remote between orders of the same class and resemblance only in fundamental features between classes of the same sub-kingdom, beyond which limit all anatomical resemblance was found to disappear—the different sub-kingdoms being formed on wholly different patterns. Furthermore, in tracing all these grades of structural relationship, naturalists were slowly led to recognise that the form which a natural classification must eventually assume would be that of a tree, wherein the constituent branches would display a progressive advance of organization from below upward.

"Now we have seen that altho this tree-like arrangement of natural groups was as suggestive as anything could well be of all the forms of life being bound together by the ties of genetic relationship, such was not the inference which was drawn from it. Dominated by the theory of special creation, naturalists either regarded the resemblance of type subordinate to type as expressive of divine ideals manifested in such creation or else contented themselves with investigating the facts without venturing to speculate upon their philosophical import. But even those naturalists who abstained from committing themselves to any theory of archetypal plans did not doubt that facts so innumerable and so universal must have been due to some one coordinating principle—that, even tho they were not able to suggest what it was, there must have been some hidden bond of connection running through the whole of organic nature. Now, as we have seen, it is manifest to evolutionists that this hidden bond can be nothing else than heredity, and, therefore, that these earlier naturalists, altho they did not know what they were doing, were really tracing the lines of genetic descent as revealed by degrees of structural resemblance—that the arborescent grouping of organic forms which their labors led them to begin, and in large measure to execute, was in fact a family tree of life.

"Here, then, is the substance of the argument from

classification. The mere fact that all organic nature thus incontestably lends itself to a natural arrangement of group subordinate to group, when due regard is paid to degrees of anatomical resemblance—this mere fact of itself tells so weightily in favor of descent with progressive modification in different lines, that even if it stood alone it would be entitled to rank as one of our strongest pieces of evidence. But, as we have seen, it does not stand alone. When we look beyond this large and general fact of all the innumerable forms of life being thus united in a tree-like system by an unquestionable relationship of some kind, to those smaller details in the science of classification which have been found most useful as guides for this kind of research, then we find that all these details, or empirically discovered rules, are exactly what we should have expected them to be, supposing the real meaning of classification to have been that of tracing lines of pedigree."

Equally illumining is the massed evidence from Paleontology. The record of the rocks as shown by fossils has always been one of the most important lines of evidence for the theory of descent. In Darwin's time the critics never grew tired of demanding proof from paleontology. A great deal of such proof has been brought forth, but paleontologists caution against expecting a complete record of the animal and plant life of the past. The record is very imperfect, "but," to quote from Metcalf's 'Organic Evolution' "so far as it goes it is an actual record. Only very unusual circumstances will secure the preservation of any animal or plant as a fossil. An organism, or portion of an organism, to be so preserved usually must be hard; it must be buried beneath soil of the proper kind and when buried must be impregnated with mineral salts or in some other way preserved from disintegration.

"When once converted into a fossil it must escape destruction at the hands of those agencies that are constantly destroying the rocks; heat, pressure, the disintegration that comes from exposure to the atmosphere, abrasion by ice

and especially erosion by water. The character of whole continents has been repeatedly changed by these agencies. No wonder then, since fossilization is rare and the destruction of fossils when once formed so easy, that our record of past faunas and floras is so scant. It is a cause for congratulation that we have so much of a record as we do possess. Thousands of species of fossil plants and animals are known, and as yet but a small portion of the earth has been searched." Attention will be given to but a few illustrations of the kind of record found in the fossil-bearing rocks, and those records naturally will be chosen that are fairly complete.

Turning to a few illustrations of the origin of particular species or organs, the same principle of gradual increase in complexity is found in coming from the older to the younger geological formations. The record of the evolution of branching antlers in the deer, as before mentioned, is fairly complete. The first deer in the early Miocene had no antlers at all. In the middle Miocene are found deer with two-pronged antlers of small size. In the upper Miocene and lower Pliocene are found three-pronged antlers somewhat larger. In the later Pliocene four-pronged and five-pronged antlers and still larger are met, while in the Pleistocene clays are seen arborescent antlers like those of the modern deer. (Fig. 21.)

Out of the mass of evidence, one further illustration must needs be sufficient. The record of the origin of the horse, worked out by American paleontologists from American fossils, is probably the best example of paleontological evidence of evolution. The horse is especially peculiar in the character of its feet and teeth, and attention will be directed to these points as shown in the accompanying illustrations. In the lower Eocene rocks an animal, Phenacodus, about the size of a fox, is found having five well-developed toes on each foot, and with short and but moderately corrugated teeth. This is one of the simplest known relatives of the hoofed mammals, and from forms

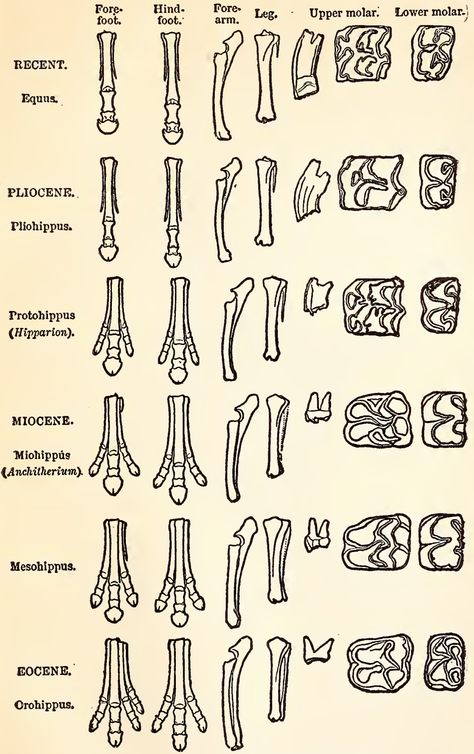


Fig. 24 —EVOLUTION OF THE HORSE.
Foot Bones and Teeth.

something like Phenacodus must have been developed the elephant, rhinoceros, hog, sheep, camel, and all the other hoofed mammals, including the horse and its long line of ancestors. Observe the steps in the transformation of the five-toed limb of a form like Phenacodus into the one-toed limb of the horse.

These are, of course, but illustrations of the kind of testimony which the study of the rocks contributes toward the proof of the theory of descent. There is, however, an enormous body of uniform evidence to prove two general facts of the highest importance in regard to the theory. The first of these general facts is that an increase

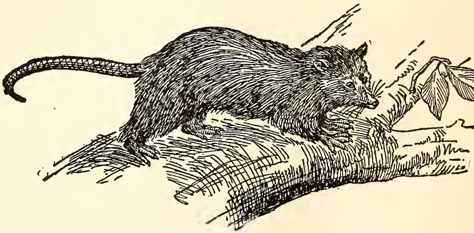


Fig. 25 —Virginia Opossum, an American Marsupial.

in the diversity of types both of plants and animals has been constant and progressive from the earliest to the latest times, as it is rational to anticipate that it must have been on the theory of descent in ever-ramifying lines of pedigree. And the second general fact is that through all these branching lines of ever-multiplying types, from the first appearance of each of them to their latest known conditions, there is overwhelming evidence of one great law of organic nature—the law of gradual advance from the general to the special, from the low to the high, from the simple to the complex.

The argument for the theory of descent deduced from a comparative study of the phenomena of paleontology—the distribution of species in time—can be supplemented by a like argument derived from a comparative study of the phenomena of geographical distribution, a distribution of

Fig. 26 —Kangaroo, an Australian Marsupial.

the species of to-day in space. In considering the distribution of living things on the earth, the first thing to be noted is that there is a decided difference in the animals and plants of different regions. At first sight, differences of climate and other physical conditions would seem to ac-

count for this, but there are many phenomena of distribution which cannot thus be explained. Countries exceedingly similar in climate and physical conditions may have quite a different fauna and flora, while those that are unlike may be characterized by similar species of plants and animals.

If regions in Australia, South Africa and western South America, between latitudes twenty-five and thirty-five degrees, are compared, it will be found that they are extremely similar in climate and physical conditions; yet it would not be possible to point out three faunas and floras more utterly dissimilar. Or, on the other hand, if the productions of South America south of latitude thirty-five be compared with those north of twenty-five degrees it will be noted that altho climatic conditions are decidedly different, these productions are incomparably more closely related than they are to the productions of Australia or Africa under almost the same climatic conditions.

The most interesting evidences of all, however, are derived from a study of distribution in combination with geological records. A good sample of this sort of evidence is to be found in the distribution of marsupials (kangaroos, bandicoots, etc.) over the earth. This singular and lowly organized type of mammals constitutes almost the sole representative of the class in Australia and New Guinea, while it is entirely unknown in Asia, Africa or Europe. It reappears in America, where several species of opossums are found. This anomaly of distribution at first was a puzzle to evolutionists, for it seemed unreasonable to postulate an earlier direct connection of these countries, which are too distant from each other to allow for migration in any other way. When, however, the geological history of the marsupial is taken into consideration the difficulty vanishes, for fossil records give abundant evidence that at one time before the more complex types of mammals came into existence the marsupials were spread over the whole eastern and western hemispheres and that

as the higher mammals developed they exterminated the more primitive marsupials, except that in Australia and New Guinea the earlier forms persisted and in America the opossums remained.

That this wide distribution of marsupials was possible in early geologic times is further supported by the fact that other geological evidence shows that Australia and New Guinea were once connected, or nearly connected, with the Malay Peninsula, making migration from the mainland possible. Moreover, the evidence shows that at that early time a very mild climate prevailed far up into the Arctic regions, hence it is not difficult to believe that migration from Europe and Asia was not unusual. There are many other kinds of evidence to be derived from the study of distribution, some of the illustrations being even more striking than those quoted, but these will be sufficient to show the relation of this kind of evidence to the doctrine of evolution.

The last line of evidence to be considered is that of 'domestication.' Every one is familiar with the great modifications which have been brought about in domestic animals, such as horses, cattle, dogs, pigeons, canary birds, etc.; in food plants, as cereals, cabbages, lettuce, radishes, berries, fruits, etc.; and in ornamental plants, as roses, carnations, dahlias, pansies and a host of other forms. Moreover, the ease with which varieties of a given form can be produced is attested to by the work of experimental breeders.

Moreover, many of these varieties differ markedly from the forms from which they were derived. "Even during the brief history of man," says Le Conte, "have been formed races of different domesticated animals and useful and ornamental plants, differing so greatly from each other that if found in the wild state they would unhesitatingly be called different species, or even in some cases different genera."

It is on this last point that objection is often taken to

this line of proof. Are even the extreme artificial varieties of any form distinct species or must they be considered but varieties of the original form? This question shows the opportunity for opposing views hinging on the definition to be given to the term species.

It might well be asked, What are the differences between the artificially-made extreme varieties (often called races), equivalent, so far as difference of form is concerned, to species, and real natural species? On this question much technical discussion could be given. It will be necessary, however, to allude here only to the most broadly recognised difference, namely, that artificially-made varieties intercross freely in breeding, producing offspring which are indefinitely fertile, while natural species do not intercross.

A great deal of study has been given this phenomenon. Darwin sums up his attitude toward it as follows: "It can no longer be maintained that varieties when crossed are invariably quite fertile. From the great difficulty of ascertaining the infertility of varieties in a state of nature, for a supposed variety, if proved to be infertile in any degree, would almost universally be ranked as a species; from man attending only to external characters in his domestic varieties, and from such varieties not having been exposed for very long periods to uniform conditions of life; from these several considerations we may conclude that fertility does not constitute a fundamental distinction between varieties and species when crossed. The general sterility of crossed species may safely be looked at, not as a special acquirement or endowment, but as incidental on changes of an unknown nature in their sexual elements."

It is true that horticulturists and breeders are intent only on making varieties along the lines of use or beauty from man's standpoint—that is, in size, structure, color, habits, etc., so-called morphological varieties—and not on making physiological species. There is, however, little doubt that mutually infertile races could be bred if the selection of individuals for breeding should be chosen with

this idea in mind. Breeders have not cared to breed with this object in view. On the contrary, cross-sterile varieties would be a positive disadvantage to them in limiting the range of their experiments.

The important point so far as evidence of the truth of organic descent is concerned is to be found in the known changes in type which have been seen to occur in domesticated animals and plants and in the diversity of forms which are known to have been derived from a few simpler types. As Professor Bailey has said, "If the prejudices of scientists respecting the so-called artificial production of species could be overcome, he could just as well draw his proofs of evolution from what has already been done with cultivated plants and domesticated animals as from similar results which might arise in the future from independent efforts."

The trend of the evidence which has been used to prove the truth of the theory of descent having been outlined, the various causes or factors which have brought about organic evolution demand attention. These bear within themselves many problems of no little subtilty and are borne out by certain correlations of facts which are of absorbing interest.

CHAPTER XII

FACTORS OF EVOLUTION—SELECTION

Altho concerning the truth of descent there is now no doubt in the minds of biologists, there are many and various views as to the causes or factors which have brought about the origin of species of plants and animals. Most prominent of the theories concerning the factors of evolution is that of Natural Selection. This theory was conceived independently by Darwin and Wallace, and strange to say, the idea came to both from the perusal of the same book, Malthus's 'Essay on Population.'

On reading this book in 1838 Darwin first conceived the idea of natural selection. But he writes, "I was so anxious to avoid prejudice that I determined not for some time to write even the briefest sketch of it. In June, 1842, I first allowed myself the satisfaction of writing a very brief abstract of my theory in pencil, in thirty-five pages, and this was enlarged during the summer of 1844 into one of 230 pages."

And Wallace writes: "In February, 1858, I was suffering from a rather severe attack of intermittent fever at Ternate, in the Moluccas, and one day while lying on my bed during the cold fit something led me to think of the 'positive checks' described by Malthus in his 'Essay on Population,' a work I had read several years before and which had made a deep and permanent impression on my mind. These checks . . . must, it occurred to me, act on animals as well as man . . . and while pondering

Fig. 27 —Variations Under Domestication.—Dogs. (Romanes.)

vaguely on this fact, there suddenly flashed upon me the idea of the survival of the fittest. In the two hours that elapsed before my ague fit was over I had thought out almost the whole of the theory, and the same evening I sketched the draft of my paper and in the two succeeding evenings wrote it out in full and sent it by the next post to Mr. Darwin."

It thus appears, to use Professor Locy's words, "that the announcement of the Darwin-Wallace theory of natural selection was made in 1858 and in the following year was published the book, the famous 'Origin of Species,' upon which Darwin had been working when he received Mr. Wallace's essay." The theory has come to bear Darwin's name and is frequently referred to as 'Darwinism.'

From time to time there appear articles and pamphlets bearing many titles announcing the decline of Darwinism, and in many periodicals this is often taken to mean that scientific men are giving up the theory of descent or evolution. Not at all. The truth is simply that some scientific men do not accept Darwin's natural selection explanation of the causes which brought about the descent of species. But Darwin's whole theory of natural selection might be discarded without injuring the general theory of descent, for the facts outlined in preceding pages have no necessary relation to theories as to causes—natural selection or other theories.

The confusion on this point is doubtless emphasized in the popular mind because Darwin not only set forth his natural selection theory in his book, the full title of which is 'The Origin of Species by Means of Natural Selection; or, The Preservation of Favored Races in the Struggle for Life,' but he also argued for the truth of evolution so well that it came to be generally accepted. However, the general idea of descent was clearly mapped out long before Darwin's time and he simply put the evidence into more convincing form. Hence evolution (the fact) is not Dar-

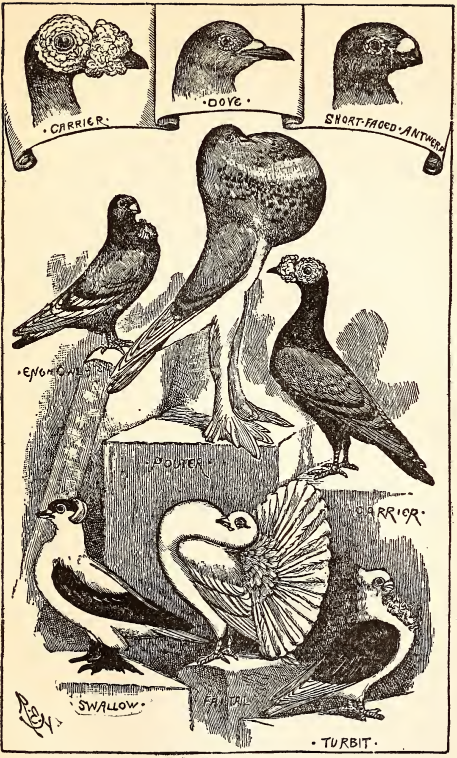


Fig. 28 —VARIATIONS UNDER DOMESTICATION.—PIGEONS. (Romanes.)

win's theory, but natural selection (a factor) deserves to bear his name.

In order to grasp the full significance of natural selection, it is first necessary to appreciate the astounding facts relating to the struggle for existence. On this point Darwin's classical statement deserves to be given. "The elder De Candolle and Lyell," he said, "have largely and philosophically shown that all organic beings are exposed to severe competition. Nothing is easier than to admit in words the truth of the universal struggle for life, or more difficult than constantly to bear this conclusion in mind. Yet unless it be thoroly ingrained in the mind, the whole economy of nature, with every fact on distribution, rarity, abundance, extinction and variation, will be dimly seen or quite misunderstood. We behold the face of nature bright with gladness, we often see superabundance of food; we do not see or we forget that the birds which are idly singing round us mostly live on insects or seeds, and are thus constantly destroying life; or we forget how largely these songsters, or their eggs, or their nestlings are destroyed by birds and beasts of prey; we do not always bear in mind that altho food may be now superabundant, it is not so at all seasons of each recurring year.

"I should premise that I use the term 'struggle for existence' in a large and metaphorical sense, including dependence of one being on another and including not only the life of the individual, but success in leaving progeny. Two canine animals, in a time of dearth, may be truly said to struggle with each other which shall get food and live. But a plant on the edge of a desert is said to struggle for life against the drought, tho more properly it should be said to be dependent on the moisture. A plant which anannually produces a thousand seeds, of which only one of an average comes to maturity, may be more truly said to struggle with the plants of the same and other kinds which already clothe the ground. The mistletoe is dependent on the apple and a few other trees, but can only in a far-

fetched sense be said to struggle with these trees, for, if too many of these parasites grow on the same tree, it languishes and dies. But several seedling mistletoes, growing close together on the same branch, may more truly be said to struggle with each other. As the mistletoe is disseminated by birds, its existence depends on them; and it may metaphorically be said to struggle with other fruit-bearing plants in tempting the birds to devour and thus disseminate its seeds. In these several senses, which pass into each other, I use for convenience' sake the general term of Struggle for Existence.

"A struggle for existence inevitably follows from the high rate at which all organic beings tend to increase. Every being which during its natural lifetime produces several eggs or seeds must suffer destruction during some period of its life and during some season or occasional year, otherwise, on the principle of geometrical increase, its numbers would quickly become so inordinately great that no country could support the product. Hence, as more individuals are produced than can possibly survive, there must in every case be a struggle for existence, either one individual with another of the same species, or with the individuals of distinct species, or with the physical conditions of life. Altho some species may be now increasing, more or less rapidly, in numbers, all cannot do so, for the world would not hold them.

"There is no exception to the rule that every organic being naturally increases at so high a rate that, if not destroyed, the earth would soon be covered by the progeny of a single pair. Even slow-breeding man has doubled in twenty-five years, and at this rate in less than a thousand years there would literally not be standing-room for his progeny. Linnæus has calculated that if an annual plant produced only two seeds—and there is no plant so unproductive as this—and their seedlings next year produced two, and so on, then in twenty years there would be a million plants. The elephant is reckoned the slowest

breeder of all known animals, and I have taken some pains to estimate its probable minimum rate of natural increase; it will be safest to assume that it begins breeding when thirty years old and goes on breeding till ninety years old, bringing forth six young in the interval and surviving till one hundred years old; if this be so, after a period of from 740 to 750 years there would be nearly nineteen million elephants alive, descended from the first pair.

"But we have better evidence on this subject than mere theoretical calculations, namely, the numerous recorded cases of the astonishingly rapid increase of various animals in a state of nature, when circumstances have been favorable to them during two or three following seasons. Still more striking is the evidence from our domestic animals of many kinds which have run wild in several parts of the world. If the statements of the rate of increase of slow-breeding cattle and horses in South America, and latterly in Australia, had not been well authenticated, they would have been incredible. So it is with plants; cases could be given of introduced plants which have become common throughout whole islands in a period of less than ten years.

"There are plants which now range in India from Cape Comorin to the Himalaya which have been imported from America since its discovery. In such cases, and endless others could be given, no one supposes that the fertility of the animals or plants has been suddenly and temporarily increased in any sensible degree. The obvious explanation is that the conditions of life have been highly favorable, and that there has consequently been less destruction of the old and young, and that nearly all the young have been enabled to breed. Their geometrical ratio of increase, the result of which never fails to be surprising, simply explains their extraordinarily rapid increase and wide diffusion in their new homes.

"In a state of nature almost every full-grown plant annually produces seed, and among animals there are very

few which do not annually pair. Hence we may confidently assert that all plants and animals are tending to increase at a geometrical ratio—that all would rapidly stock every station in which they could anyhow exist—and that this geometrical tendency to increase must be checked by destruction at some period of life. Our familiarity with the larger domestic animals tends, I think, to mislead us; we see no great destruction falling on them, but we do not keep in mind that thousands are annually salughtered for food, and that in a state of nature an equal number would have somehow to be disposed of.

"The only difference between organisms which annually produce eggs or seeds by the thousand and those which produce extremely few is that the slow-breeders would require a few more years to people, under favorable conditions, a whole district, let it be ever so large. The condor lays a couple of eggs and the ostrich a score, and yet in the same country the condor may be the more numerous of the two; the Fulmar petrel lays but one egg, yet it is believed to be the most numerous bird in the world. One fly deposits hundreds of eggs and another, like the hippobosca, a single one; but this difference does not determine how many individuals of the two species can be supported in a district. A large number of eggs is of some importance to those species which depend on a fluctuating amount of food, for it allows them rapidly to increase in number.

"But the real importance of a large number of eggs or seeds is to make up for much destruction at some period of life; and this period in the great majority of cases is an early one. If an animal can in any way protect its own eggs or young, a small number may be produced, and yet the average stock be fully kept up; but if many eggs or young are destroyed, many must be produced or the species will become extinct. It would suffice to keep up the full number of a tree which lived on an average for a thousand years if a single seed were produced once in a

thousand years, supposing that this seed were never destroyed and could be insured to germinate in a fitting place. So that, in all cases, the average number of any animal or plant depends only indirectly on the number of its eggs or seeds.

"In looking at Nature, it is most necessary to keep the foregoing considerations always in mind—never to forget that every single organic being may be said to be striving to the utmost to increase in numbers; that each lives by a struggle at some period of its life; that heavy destruction inevitably falls either on the young or old during each generation or at recurrent intervals. Lighten any check, mitigate the destruction ever so little, and the number of the species will almost instantaneously increase to any amount."

Many marvelous facts concerning the rapid increase of plants and animals have been collected since Darwin's time. Jordan and Kellogg give many instances and among them the following: "It is said that the conger eel lays 15,000,000 eggs yearly. If each hatched and the conger grew to maturity, in a few years there would be no room for any other kind of fish in the sea. The codfish has been known to produce 9,100,000 eggs each year. If each egg were to develop, in ten years the sea would be solidly full of codfish. The female quinnat salmon of the Columbia ascends the river at the age of about four years and lays 4,000 eggs, after which she dies. Half these eggs develop into males. If each female egg came to maturity, we should have at the end of fifty years 8,000,000,000,000,000,000,000,000,000,000,000,000,000,000,000 female salmon and as many males as the offspring of a single pair. It takes about one hundred of these salmon to weigh a ton. Could all these fishes develop, in a very short time there would be no room for them in all the rivers of the North nor in all the waters of the sea."

The records of the spread of the English sparrow in America and of rabbits in Australia are splendid examples

of the possible rate of multiplication. Professor Sidney Dickinson gives the following notes on the rabbit of Australia: "The fecundity of the rabbit is amazing, and his invasion of remote districts swift and mysterious. Careful estimates show that under favorable conditions a pair of Australian rabbits will produce six litters a year, averaging five individuals each. As the offspring themselves begin breeding at the age of six months, it is shown that, at this rate, the original pair might be responsible in five years for a progeny of over twenty millions. That the original score that were brought to the country have propagated after some such ratio, no one can doubt who has seen the enormous hordes that now devastate the land in certain districts. In all but the remoter sections the rabbits are now fairly under control; one rabbiter with a pack of dogs supervises stations where one hundred were employed ten years ago, and with ordinary vigilance the squatters have little to fear. Millions of the animals have been killed by fencing in the water holes and dams during a dry season, whereby they died of thirst and lay in enormous piles against the obstructions they had frantically and vainly striven to climb, and poisoned grain and fruit have killed myriads more."

These examples must suffice. Any other animal or plant would illustrate the same principle, for each increases at a rate which would make it cover the earth in a comparatively short time. That this is not the case is due to this check known as the Struggle for Existence. This was well known before Darwin's time, but he was the first to see its great importance in the development of plant and animal species.

The nature of the checks to increase is often complex. One has but to watch a bit of natural land to see them working. Climatic conditions play an important part in limiting the increase, and a wet season will make some crops exceedingly light and many insects very rare. Overcrowding limits the supply of food and other needful

things, and hence some plants are 'choked' and many animals starve. Serving as prey to other animals causes enormous destruction of both animals and plants, for thousands of insects and other animal enemies must have food. Thus Darwin in an observational experiment noted that out of 357 weed seedlings under observation 295 were destroyed by insects alone. Various bacterial and other fungous diseases destroy countless thousands of plants and animals in a single day, and it is well known that various diseases due to animal and vegetable parasites are great checks to increase in most species of vertebrate animals.

In some cases the struggle is with the elements, in others special enemies constitute the most important check. The history of the cottony-cushion scale in America, described by Miall, offers a good example of a special check of this sort. "About the year 1880 the orange groves of South California seemed to be infected with a kind of leprosy. White patches appeared on the trunks and branches, which at length ran together and covered the bark, the leaves turned yellow, and no fruit could be ripened. The plague spread with rapidity, and all the time-honored remedies were found to be ineffectual. It was soon made known that the symptoms described were due to the attack of a scale-insect, known in America as the fluted scale, or cottony-cushion scale.

"This formidable plague gradually increased its range, in spite of the vigorous use of poisonous washes. It was not till 1888 that an effectual remedy was found. The late C. V. Riley, Entomologist to the United States Department of Agriculture, had anxiously considered the ways of checking the fluted scale. He found out that it came from Australia, where it infested the bushes called wattles (Acacias); that it had been introduced into California about 1868, probably on Acacias; that in its native country it was not a serious plague, altho no remedies were employed. He concluded that it must be kept down in Australia by natural enemies of some kind which did not exist

in California and that the real policy was to discover and import these remedies, whether parasitic or predatory.

"In 1888 Riley sent a trained entomologist, Albert Koebele, to visit Australia, examine the gardens and report. He found that the fluted scale, tho widespread, was kept in check by several insect foes. The most promising of these for Californian purposes was considered to be an Australian lady-bird known to naturalists as 'Vedalia cardinalis.' This beetle, both as larva and adult, greedily devours the scale-insect and its eggs, preys upon no other species and is very prolific. Koebele was diligent in procuring an abundant supply of Vedalia. The lady-birds were soon distributed and found plenty of occupation. In a year and a half they had practically rid California of the pest."

Nor is this case of the cottony-cushion scale alone. Any text-book of economic entomology will cite hundreds of cases of similar kinds. At the present time the United States entomologist, Dr. L. O. Howard, is searching for a special enemy supposed to keep in check the gipsy moth, now so destructive in Massachusetts.

Such are some of the influences known to affect plants and animals in the struggle for existence. It is clearly to be seen that the whole question of the relation of the individual to its environment—that is, the problems of plant and animal ecology—are involved in the struggle for existence and in the checks to the tendency to overwhelming increase. Science has only begun to understand these problems of ecology. However, the principle of the struggle for existence is not affected because its causes are not known. This much is certain: organisms tend to increase rapidly; an untiring struggle for existence exists; the vast majority of individuals perish as a result of this struggle with the environment—the result being as Darwin believed that those organisms best fitted to their environment survive—*i.e.,* the struggle for existence leads naturally to the survival of the fittest. This is natural selection. Nature—

meaning the sum total of the environmental factors which affect an organism—selects those individuals best fitted to the environment. How this works in detail is best explained after some consideration of the variation of organisms.

The foundation of the Darwinian theory is the variability of species, and it is quite useless to attempt even to understand that theory, much less to appreciate the completeness of the proof of it, unless a clear conception of the nature and extent of this variability is obtained. Variation in the state of nature has been discussed by Alfred Russell Wallace in 'Darwinism.' Mr. Wallace shows in some detail that individual variability is a general character of all common and widespread species of animals or plants; and, further, that this variability extends, so far as is known, to every part and organ, whether external or internal, as well as to every mental faculty, and that each part or organ varies to a considerable extent independently of other parts. Again, he shows by abundant evidence that the variation that occurs is very large in amount—usually reaching 10 or 20 and sometimes even 25 per cent. of the average size of the varying part.

But a few examples can be given to illustrate this feature of life. The variability of plants is notorious, being proved not only by the endless variations which occur whenever a species is largely grown by horticulturists, but also by the great difficulty that is felt by botanists in determining the limits of species in many large genera. As an example may be taken the roses. In Mr. Baker's 'Revision of the British Roses' he includes under the single species Rosa canina—the common dog-rose—no less than twenty-eight named varieties distinguished by more or less constant characters and often confined to special localities, and to these are referred about seventy of the species of British and continental botanists.

Concerning individual variation, the distinguished botanist, Alp. de Candolle, made a special study of the oaks of

the whole world and has stated some remarkable facts as to their variability. He declares that on the same branch of oak he has noted the following variations: In the length of the petiole, as one to three; in the form of the leaf, being either elliptical or obovoid; in the margin being entire, or notched, or even pinnatifid; in the extremity being acute or blunt; in the base being sharp, blunt or cordate; in the surface being pubescent or smooth; the perianth varies in depth and lobing; the stamens vary in number, independently; the anthers are mucronate or blunt; the fruit stalks vary greatly in length, often as one to three; the number of fruits varies; the form of the base of the cup varies; the scales of the cup vary in form; the proportions of the acorns vary; the times of the acorns ripening and falling vary. Besides this, many species exhibit well-marked varieties which have been described and named.

Among birds copious evidence of variation is found. The most systematic observations on the individual variation of birds have been made by J. A. Allen in his remarkable memoir, 'On the Mammals and Winter Birds of East Florida.' He says: "The facts of the case show that a variation of from 15 to 20 per cent. in general size, and an equal degree of variation in the relative size of different parts, may be ordinarily expected among specimens of the same species and sex, taken at the same locality, while in some cases the variation is even greater than this." He then goes on to show that each part varies to a considerable extent independently of the other parts, so that when the size varies, the proportions of all the parts vary, often to a much greater amount. The wing and tail, for example, besides varying in length, vary in the proportionate length of each feather, and this causes their outline to vary considerably in shape. The bill also varies in length, width, depth and curvature.

Even tho one has not been impressed with the great variety of individuals in the state of nature, variation in

domesticated plants and animals and the efficacy of artificial selection in producing varieties of the different species of plants and animals cannot have escaped notice. The following paragraphs are taken from Mr. Wallace's account of variation in domesticated plants and animals:

"Every one knows that in each litter of kittens or of puppies no two are alike. Even in the case in which several are exactly alike in colors, other differences are always perceptible to those who observe them closely. They will differ in size, in the proportions of their bodies and limbs, in the length or texture of their hairy covering and notably in their disposition. They each possess, too, an individual countenance, almost as varied when closely studied as that of a human being. The same thing occurs in the vegetable kingdom. All plants raised from seed differ more or less from each other. In every bed of flowers or of vegetables we shall find, if we look closely, that there are countless small differences in the size, in the mode of growth, in the shape or color of the leaves, in the form, color or markings of the flowers, or in the size, form, color or flavor of the fruit. These differences are usually small, but are yet easily seen, and in their extremes are very considerable; and they have this important quality, that they have a tendency to be reproduced, and thus by careful breeding any particular variation or group of variations can be increased to an enormous extent—apparently to any extent not incompatible with the life, growth and reproduction of the plant or animal.

"The way this is done is by artificial selection, and it is very important to understand this process and its results. Suppose we have a plant with a small edible seed and we want to increase the size of that seed. We grow as large a quantity of it as possible, and when the crop is ripe we carefully choose a few of the very largest seeds or we may by means of a sieve sort out a quantity of the largest seeds. Next year we sow only these large seeds, taking care to give them suitable soil and manure, and the result is found

to be that the average size of the seeds is larger than in the first crop and that the largest seeds are now somewhat larger and more numerous. Again sowing these, we obtain a further slight increase of size, and in a very few years we obtain a greatly improved race, which will always produce larger seeds than the unimproved race, even if cultivated without any special care. In this way all our fine sorts of vegetables, fruits and flowers have been obtained, all our choice breeds of cattle or of poultry, our wonderful race-horses and our endless varieties of dogs. It is a very common but mistaken idea that this improvement is due to crossing and feeding in the case of animals, and to improved cultivation in the case of plants. Crossing is occasionally used in order to obtain a combination of qualities found in two distinct breeds, and also because it is found to increase the constitutional vigor; but every breed possessing any exceptional quality is the result of the selection of variations occurring year after year and accumulated in the manner just described. Purity of breed, with repeated selection of the best varieties of that breed, is the foundation of all improvement in our domestic animals and cultivated plants.

"The experience of breeders and cultivators proves that variation is the rule instead of the exception, and that it occurs, more or less, in almost every direction. This is shown by the fact that different species of plants and animals have required different kinds of modifications to adapt them to our use, and we have never failed to meet with variation in that particular direction, so as to enable us to accumulate it and so to produce ultimately a large amount of change in the required direction. Our gardens furnish us with numberless examples of this property of plants. In the cabbage and lettuce we have found variation in the size and mode of growth of the leaf, enabling us to produce by selection the almost innumerable varieties, some with solid heads of foliage quite unlike any plant in a state of nature, others with curiously wrinkled leaves

like the savoy, others of a deep purple color used for pickling. From the very same species as the cabbage have arisen the broccoli and cauliflower, in which the leaves have undergone little alteration, while the branching heads of flowers grow into a compact mass forming one of our most delicate vegetables.

"The most remarkable varieties are afforded by the apple, and some account of these will be given as illustrating the effects of slight variations accumulated by selection. All our apples are known to have descended from the common crab of our hedges, and from this at least a thousand distinct varieties have been produced. These differ greatly in the size and form of the fruit, in its color, and in the texture of the skin. They further differ in the time of ripening, in their flavor, and in their keeping properties; but apple-trees also differ in many other ways.

"Coming now to our domesticated animals, we find still more extraordinary cases; and it appears as if any special quality or modification in an animal can be obtained if we only breed it in sufficient quantity, watch carefully for the required variations, and carry on selection with patience and skill for a sufficiently long period. Thus in sheep we have enormously increased the wool, and have obtained the power of rapidly forming flesh and fat; in cows we have increased the production of milk; in horses we have obtained strength, endurance, or speed, and have greatly modified size, form, and color; in poultry we have secured various colors of plumage, increase of size, and almost perpetual egg-laying; and in dogs and pigeons marvelous changes have been effected."

The facts of individual variation from the viewpoint of a prominent American botanist will supplement the statements of Darwin and Wallace. Professor L. H. Bailey based his lectures on 'Plant Breeding' on the universal difference in nature. He says: "No two living things are exact counterparts, for no two are born into exactly the same conditions and experiences. Every liv-

ing object has individuality; that is, there is something about it which enables the acute observer to distinguish it from all other objects, even of the same class or species. Every plant in a row of lettuce is different from every other plant, and the gardener, when transplanting them, selects out, almost unconsciously, some plants which please him and others which do not. If one were to make the effort, he would find that it is possible to distinguish differences between every two spears of grass in a meadow or every two heads of wheat in a grain-field.

"All this is equivalent to saying that plants are infinitely variable. The ultimate causes of all this variation are beyond the purpose of the present discussion, but it must be evident to the reflective mind that these differences are the means of adapting the innumerable individuals to every little difference or advantage in the environment in which they live.

"If no two plants are anywhere alike, then it is not strange if now and then some departure, more marked than common, is named and becomes a garden variety. We have been taught to feel that plants are essentially stable and inelastic, and that any departure from the type is an exception, and calls for immediate explanation. The fact is, however, that plants are essentially unstable and plastic, and that variation between the individuals must everywhere be expected. This erroneous notion of the stability of organisms comes of our habit of studying what we call species. We set for ourselves a type of plant or animal and group about it all those individuals which are more like this type than they are like any other, and this group we name a species. Nowadays, the species is regarded as nothing more than convenient and arbitrary expression for classifying our knowledge of the forms of life, but the older naturalists conceived that the species is the real entity or unit in nature, and we have not yet wholly outgrown the habit of mind which was born of that fallacy.

"Nature knows nothing about species; she is concerned with the individual, the ultimate unit. This individual she molds and fits into the chinks of environment, and each individual tends to become the more unlike its birthmates the more the environments of the various individuals are unlike. I would impress upon you, therefore, the importance of the individual plant, rather than the importance of the species; for thereby we put ourselves as nearly as possible in a sympathetic attitude with Nature, and, resting upon the ultimate object of her concern, we are able to understand what may be conceived to be her motive in working out the problems of life."

It should be noted that Darwin did not give much attention to the causes of variation. He simply gathered together the data to show that organisms are highly variable. Given the facts of the high variability of individuals of all plants and animals, and the intense struggle for existence, how will this struggle act in regard to variation? Can the principle of selection, which is seen to be so potent in the hands of man in artificial selection, apply to organisms in a state of nature? These are essentially the questions which Darwin asked, and his own answer, now become a classic in science, is still the most satisfactory.

"I think we shall see," he says, "that it (the principle of selection) can act most efficiently. Let the endless number of slight variations and individual differences occurring in our domestic productions, and in a lesser degree in those under nature, be borne in mind; as well as the strength of the hereditary tendency. Under domestication, it may be truly said that the whole organization becomes in some degree plastic. But the variability, which we almost universally meet with in our domestic productions, is not directly produced, as Hooker and Asa Gray have well remarked by man; he can neither originate varieties nor prevent their occurrence; he can only preserve and accumulate such as do occur. Unintentionally

he exposes organic beings to new and changing conditions of life, and variability ensues; but similar changes of conditions might and do occur under nature. Let it also be borne in mind how infinitely complex and close-fitting are the mutual relations of all organic beings to each other and to their physical conditions of life; and consequently what infinitely varied diversities of structure might be of use to each being under changing conditions of life.

"Can it, then, be thought improbable, seeing that variations useful to man have undoubtedly occurred, that other variations useful in some way to each being in the great and complex battle of life should occur in the course of many successive generations? If such do occur, can we doubt (remembering that many more individuals are born than can possibly survive) that individuals having any advantage, however slight, over others, would have the best chance of surviving and of procreating their kind? On the other hand, we may feel sure that any variation in the least degree injurious would be rigidly destroyed. This preservation of favorable individual differences and variations, and the destruction of those which are injurious, I have called Natural Selection, or the Survival of the Fittest. Variations neither useful nor injurious would not be affected by natural selection, and would be left either a fluctuating element, as perhaps we see in certain polymorphic species, or would ultimately become fixed, owing to the nature of the organism and the nature of the conditions.

"We have good reason to believe that changes in the conditions of life give a tendency to increased variability; and this would manifestly be favorable to natural selection, by affording a better chance of the occurrence of profitable variations. Unless such occur, natural selection can do nothing. Under the term of 'variations' it must never be forgotten that mere individual differences are included. As man can produce a great result with

his domestic animals and plants by adding up in any given direction individual differences, so could natural selection, but far more easily, from having incomparably longer time for action.

"Nor do I believe that any great physical change, as of climate, or any unusual degree of isolation to check immigration, is necessary in order that new and unoccupied places should be left, for natural selection to fill up by improving some of the varying inhabitants. For as all the inhabitants of each country are struggling together with nicely balanced forces, extremely slight modifications in the structure or habits of one species would often give it an advantage over others; and still further modifications of the same kind would often still further increase the advantage, as long as the species continued under the same conditions of life and profited by similar means of subsistence and defense.

"As man can produce, and certainly has produced, a great result by his methodical and unconscious means of selection, what may not natural selection effect? Man can act only on external and visible characters. Nature, if I may be allowed to personify the natural preservation or survival of the fittest, cares nothing for appearances, except in so far as they are useful to any being. She can act on every internal organ, on every shade of constitutional difference, on the whole machinery of life. Man selects only for his own good: Nature only for that of the being which she tends. Every selected character is fully exercised by her, as is implied by the fact of their selection. Man keeps the natives of many climates in the same country; he seldom exercises each selected character in some peculiar and fitting manner; he feeds a long and a short beaked pigeon on the same food; he does not exercise a long-backed or long-legged quadruped in any peculiar manner; he exposes sheep with long and short wool to the same climate. He does not allow the most vigorous males to struggle for the females. He does

not rigidly destroy all inferior animals, but protects during each varying season, as far as lies in his power, all his productions. He often begins his selection by some half-monstrous form; or at least by some modification prominent enough to catch the eye or to be plainly useful to him. Under nature, the slightest differences of structure or constitution may well turn the nicely balanced scale in the struggle for life, and so be preserved. How fleeting are the wishes and efforts of man! how short his time! and consequently how poor will be his results, compared with those accumulated by Nature during whole geological periods! Can we wonder, then, that Nature's productions should be far 'truer' in character than man's productions; that they should be infinitely better adapted to the most complex conditions of life, and should plainly bear the stamp of far higher workmanship?

"It may metaphorically be said that natural selection is daily and hourly scrutinizing, throughout the world, the slightest variations; rejecting those that are bad, preserving and adding up all that are good; silently and insensibly working, whenever and wherever opportunity offers, at the improvement of each organic being in relation to its organic and inorganic conditions of life. We see nothing of these slow changes in progress until the hand of time has marked the lapse of ages, and then so imperfect is our view into long-past geological ages that we see only that the forms of life are now different from what they formerly were.

"In order that any great amount of modification should be effected in a species, a variety when once formed must again, perhaps after a long interval of time, vary or present individual differences of the same favorable nature as before; and these must be again preserved, and so onward step by step. Seeing that individual differences of the same kind perpetually recur, this can hardly be considered as an unwarrantable assumption. But whether it is true, we can judge only by seeing how far the hypothe-

sis accords with and explains the general phenomena of nature. On the other hand, the ordinary belief that the amount of possible variation is a strictly limited quantity is likewise a simple assumption.

"Altho natural selection can act only through and for the good of each being, yet characters and structures, which we are apt to consider as of very trifling importance, may thus be acted on. When we see leaf-eating insects green, and bark-feeders mottled-gray, the alpine ptarmigan white in winter, the red grouse the color of heather, we must believe that these tints are of service to these birds and insects in preserving them from danger. Grouse, if not destroyed at some period of their lives, would increase in countless numbers; they are known to suffer largely from birds of prey; and hawks are guided by eyesight to their prey—so much so that on parts of the Continent persons are warned not to keep white pigeons, as being the most liable to destruction. Hence natural selection might be effective in giving the proper color to each kind of grouse, and in keeping that color, when once acquired, true and constant. Nor ought we to think that the occasional destruction of an animal of any particular color would produce little effect; we should remember how essential it is in a flock of white sheep to destroy a lamb with the faintest trace of black.

"In looking at many small points of difference between species, which, as far as our ignorance permits us to judge, seem quite unimportant, we must not forget that climate, food, etc., have no doubt produced some direct effect. It is also necessary to bear in mind that owing to the law of correlation, when one part varies, and the variations are accumulated through natural selection, other modifications, often of the most unexpected nature, will ensue.

"As we see that those variations which, under domestication, appear at any particular period of life, tend to reappear in the offspring at the same period—for instance,

in the shape, size and flavor of the seeds of the many varieties of our culinary and agricultural plants; in the caterpillar and cocoon stages of the varieties of the silk-worm; in the eggs of poultry, and in the color of the down of their chickens; in the horns of our sheep and cattle when nearly adult—so in a state of nature natural selection will be enabled to act on and modify organic beings at any age, by the accumulation of variations profitable at that age, and by their inheritance at a corresponding age.

"If it profit a plant to have its seeds more and more widely disseminated by the wind, I can see no greater difficulty in this being effected through natural selection than in the cotton planter increasing and improving by selection the down in the pods on his cotton-trees. Natural selection may modify and adapt the larva of an insect to a score of contingencies wholly different from those which concern the mature insect; and these modifications may effect, through correlation, the structure of the adult. So, conversely, modifications in the adult may affect the structure of the larva; but in all cases natural selection will ensure that they shall not be injurious; for if they were so, the species would become extinct.

"Natural selection will modify the structure of the young in relation to the parent, and of the parent in relation to the young. In social animals it will adapt the structure of each individual for the benefit of the whole community, if the community profits by the selected change. What natural selection cannot do is to modify the structure of one species, without giving it any advantage, for the good of another species; and tho statements to this effect may be found in works of natural history, I cannot find one case which will bear investigation. A structure used only once in an animal's life, if of high importance to it, might be modified to any extent by natural selection; for instance, the great jaws possessed by certain insects, used exclusively for opening the

cocoon; or the hard tip to the beak of unhatched birds, used for breaking the egg.

"It may be well here to remark that with all beings there must be much fortuitous destruction, which can have little or no influence on the course of natural selection. For instance, a vast number of eggs or seeds are annually devoured, and these could be modified through natural selection only if they varied in some manner which protected them from their enemies. Yet many of these eggs or seeds would, perhaps, if not destroyed, have yielded individuals better adapted to their conditions of life than any of those which happened to survive. So again, a vast number of mature animals and plants, whether or not they be the best adapted to their conditions, must be annually destroyed by accidental causes, which would not be in the least degree mitigated by certain changes of structure or constitution which would in other ways be beneficial to the species.

"But let the destruction of the adults be ever so heavy, if the number which can exist in any district be not wholly kept down by such causes—or again, let the destruction of eggs or seeds be so great that only a hundredth or a thousandth part are developed—yet of those which do survive the best adapted individuals, supposing that there is any variability in a favorable direction, will tend to propagate their kind in larger numbers than the less well adapted. If the numbers be wholly kept down by the causes just indicated, as will often have been the case, natural selection will be powerless in certain beneficial directions; but this is no valid objection to its efficiency at other times and in other ways, for we are far from having any reason to suppose that many species ever undergo modification and improvement at the same time in the same area."

In concluding this sketch of Darwin's Natural Selection theory it should be noted that Darwin believed natural selection to be the most important, but not the sole, factor

in producing new forms of organisms. His later followers, especially of the Weismann school, have held natural selection to be the all-sufficient factor of evolution. It will be necessary to return to this in discussing modern criticisms of Darwinism. Summarizing the essential points in the natural selection theory, Jordan and Kellogg say that: "Of all the various factors of organic evolution, the one which has been most relied on as the great determining agent is that called Natural Selection, the survival of the individuals best fitted for the conditions of life, with the inheritance of those species-forming adaptations in which fitness lies. The primal initiative is not in natural selection, but in variation—germinal and individual. This may be slight variation (fluctuation) or large deviation (saltation), but in any case, all difference in species or race must first be individual. The impulse to change, once arisen, is continued through heredity. From natural selection arises the choice among different lines of descent, the adaptive tending to exclude the non-adaptive, while traits which are neither helpful nor hurtful, but simply indifferent, may be borne along by the current of adaptive characters. Finally, separation or isolation tends to preserve a special line of heredity from being merged in the mass which constitutes the parent stock or species. Without individual variation no change could take place; all organisms would be identical in structure."

Altho the Darwinian theory has been subject to no popularly recognised attack during the last quarter of a century, nevertheless there has been accumulating a mass of criticism of it. Only a sketch of some of the leading criticisms can be presented. These will be taken in large measure from Kellogg's 'Darwinism To-day.'

"Among the critics of the selection theories," he says, "we must note two groups, differing in the character of their criticism more in degree than in kind, perhaps, but still importantly differing. One group denies in toto any

effectiveness or capacity for species-forming on the part of natural selection, while the other group, a larger one, sees in natural selection an effective factor in directing or controlling the general course of descent, holding it to adaptive lines, but denies it outright any such 'Allmacht' of species control as the more eager selectionists, the so-called neo-Darwinians or Weismannians, credit it with. This larger group of critics sees in natural selection an evolutionary factor capable of initiating nothing, dependent wholly for any effectiveness on some primary factor or factors controlling the origin and direction of variation, but wholly capable of extinguishing all unadapted, unfit lines of development, and in this way of exercising decisive final control over the general course of descent—*i.e.*, organic evolution.

"The general impression left on one after a considerable course of anti-Darwinian reading is that there is a very real and effective amount of destructive criticism for Darwinians to meet; and at the same time a curious paucity of satisfactory or at all convincing substitutionary theory offered by the anti-Darwinians to replace that which they are attempting to dethrone. The situation illustrates admirably the varying worth of a few facts. A few stubborn facts of the wrong complexion are fatal things for a theory; they are immensely effective offensive weapons. But these same few facts make a pitiable showing when they are called on to support a theory of their own.

"It was exactly the greatest part of Darwin's greatness, it seems to me, that he launched his theory only after making the most remarkable collection of facts yet gathered together in biological science by any one man. Testing his theory by applying to it successively fact after fact, group after group, and category after category of facts, he convinced himself of the theory's consonance with all this vast array of observed biological actuality.

"Compare the grounding of any of the now offered re-

placing theories with the preparation and founding of Darwinism. In 1864 von Kölliker, a great biologist, convinced of the incapacity of natural selection to do the work assigned it by its founders and friends, suggested a theory of the origin of species by considerable leaps; in 1899 Korschinsky, on the basis of some few personal observations and the compiling of some others, definitely formulated a theory of species-forming by sudden considerable variations, namely, mutations; in 1901 and 1903 appeared the two volumes of De Vries's 'Die Mutationstheorie,' in which are revealed the results of long years of careful personal observation, in truly Darwinian manner, directed toward the testing and better grounding of this mutations-theory of species-origin. The results are: out of many plant species studies a few show at certain times in the course of numerous generations a behavior in accordance with the demands of a theory of species-forming by sudden definitive modification; that is, species-forming by mutations.

"The mutations-theory thus launched is offered as a substitute for the natural selection theory obviously weakening under the fire of modern scientific criticism. But however effective De Vries's facts are in proving the possibility of the occurrence of other variations than those fortuitous ones occurring in continuous series from mean to opposite extremes which Darwin recognised as the basis of species-forming, and however effective they are in proving the actual production of three or six or ten species by mutation, and however effective in both these capacities they are as weapons of attack on the dominance of the Darwinian theory of species-making, how really inadequate are they to serve as the basis of a great all-answering theory explaining in a causo-mechanical way the facts of descent, or even the primary facts of general species-forming.

"The natural selection theory, as an all-sufficient explanation of adaptation and species-forming, has always

had a weakness at its base; it depends absolutely, of course, on the preexistence of variations, but it itself has no influence whatever on the origin or control of these variations to give birth to other individuals. Now one of the chief problems in biology is exactly that of the origin, the causes, and the primary control of these congenital variations.

"Three principal explanations, no one of them experimentally proved or even fairly tested as yet, have been given of this actually occurring congenital variation, viz., (1) that there exists in the germ-plasm an inherent tendency or capacity to vary so that there is inevitable variation in all individuals produced from germ-plasm, this variation being wholly fortuitous and fluctuating according to some (the belief of Darwin and his followers), or, according to others, this variation following certain fixed or determinate lines (determinate variation, orthogenetic variation, etc.); (2) that amphimixis—*i.e.,* biparental parentage—is the principal cause of variation, it seeming logical to presume that individuals produced from germ-cells derived from the fusion of germ-plasm coming from two individuals more or less unlike would differ slightly from either of the parental individuals; and (3) that congenital variation is due to the influence of the ever-varying environment of the germ-cell producing individuals.

"The objections to any one of these theories may be very pertinent, as when one says regarding the first that calling a thing 'inherent' is not clearing up in any degree a phenomenon for which we are demanding a causo-mechanical explanation; or of the second, that it has been proved that individuals produced parthenogenetically—that is, from an unmated mother—vary, and in some cases vary even more than do other individuals of the same species produced by amphimixis; or of the third, that as far as our study of the actual processes and mechanism of the production of germ-cells and of embryos has gone,

we have found no apparent means whereby this influence of the ambient medium can be successfully impressed on the germ-plasm. But however pertinent the objections to the why of variation may be, they do not in any way invalidate the fact that variations do continuously and inevitably occur in all individuals, and that while many of these variations are recognisably such as have been impressed on the individual during its personal development as immediate results of varying temperature, amount or kind of food, degree of humidity, etc., to which it may be exposed in its young life, others seem wholly inexplicable on a basis of varying individual environment, and are certainly due to some antenatal influence acting on the germ-plasm from which the embryo is derived.

"Now, the natural selection theory, in its Darwinian and neo-Darwinian form, presupposes fortuitously occurring congenital variations of practically infinite variety in all parts of all organisms. Actual observation shows that all parts of all organisms do vary, and that they vary congenitally; that is, independently of any immediate influence during development exercised from without by environmental conditions, as well as in response to these environmental influences, and finally, that in many cases this variation is fortuitous—that is, that it occurs according to the laws of chance.

"The industrious statistical study of variations, including the tabulation of the variation condition in long series of individuals of the same species or race, and the mathematical formulation of this variation condition, have shown that in many specific cases, studied in numerous kinds of animal and plant forms, the character of the variation in any particular character may be truly represented (with close approximation) by the mathematical expression and curve which would exactly define the condition in which the variation would exist if it actually followed the law of error. It is these continuous series of slight variations, these variously called fluctuating, in-

dividual, or Darwinian variations, occurring in all organisms at all times, and often following in their occurrence the laws of chance, on which Darwin's theory of species-forming by natural selection is based.

"But this same industrious statistical and quantitative study of variation which has proved that some variations do occur regularly, fluctuating around a mean or mode, has shown, as well, that in many cases the variations distinctly tend to heap up on one side or the other of the mean; that is, that they tend to occur along certain lines or toward certain directions rather than uniformly out in all directions. Also it is true—and this has, of course, been long known—that by no means all variations are so slight nor in such perfectly gradatory or continuous series as is true of the gradatory Darwinian variations. 'Sports' have been known to breeders of plants and animals ever since plant and animal breeding began. Bateson has filled a large book with records of 'discontinuous variations' in animals; variations, that is, of large size and not occurring as members of continuous gradatory series. So that biologists are acquainted with many cases of variation that seem to be of a kind, or to exhibit a tendency to institute special directions of development, and thus not to be of the simple, non-initiating, inert character of the fortuitous, slight, fluctuating variations, among which natural selection is presumed to choose those that are to become the beginnings of new lines of modification and descent. Many biologists believe firmly that variations occur in many special cases, if not in most cases, only along certain special lines. Paleontologists believe, practically as a united body, that variation has followed fixed lines through the ages; that there has been no such unrestricted and utterly free play of variational vagary as the Darwinian natural selection theory presupposes.

"Now it is at least obvious that natural selection is absolutely limited in its work to the material furnished

by variation, so that if variation occurs in any cases along certain determinate lines selection can do no more than make use of these lines. Indeed, if variation can occur persistently along determinate lines, natural selection's function in controlling evolution in such cases is limited to the police power of restricting or inhibiting further development along any one or more of these lines which are of a disadvantageous character; that is, a character which handicaps or destroys the efficiency of its members in the struggle for life. The question in many men's mouths to-day is, Why may not variation be the actual determinant factor in species-forming, in descent? It actually is, respond many biologists and paleontologists. Even Darwin believed such determinate variation to occur, as is indicated by repeated statements in the 'Origin of Species.'"

This problem of the existence or non-existence of determinate variations is one of the most important matters in connection with the whole great problem of descent; that is, of evolution. It is the basic problem of evolution, for it is the problem of beginnings. Selection, isolation, and the like factors are conditions of species-forming; variation is a prerequisite. True variation must have its causes, and these causes are to be determined before an actual causo-mechanical explanation of evolution can ever be found. But the determination of the relation of variation to species-forming is certainly the first step now necessary in our search for the basic factors, the real first cause of species change.

Space will not permit analysis of the general lines of objections raised in the foregoing. These objections have led many biologists to the totally ante-Darwinian position that the struggle for existence and the corresponding selection of the fit are not factors of evolution. But perhaps the majority of biologists who recognise the objections cited are inclined to belief in natural selection as the great 'conserving factor of evolution' while allowing

that it does not create new forms. To quote from T. H. Morgan, ". . . the theory of natural selection has nothing to do with the origin of species, but with the survival of already formed species. Not selection of the fittest individuals, but the survival of the sufficiently fit species."

In summarizing the present-day standing of the Darwinian theory, Kellogg says: "I think I speak fairly in saying that the believers and defenders of the natural selection theory to-day admit in large measure the validity of those criticisms which are directed at the incapacity of Darwinism, in its long familiar form, to account for the development of variations and modifications up to the advantageous or disadvantageous stage. They admit, also, the actual existence, and in abundant measure, of species differences which are of indifferent character—that is, of no special utility—and make the consequent admission that such species differences cannot for the most part be explained by natural selection. And they also concede, or at least most of them, including Weismann, do, the force of the criticism that the assumption of the occurrence of the right variations at the right time is a necessity for the development by selection of many, if not most, specializations of qualitative and of coadaptive character, which assumption in turn demands an explanation of causes anterior to selection.

"And finally, most selectionists concede that selection cannot make new species by relying on the extremes of series of fluctuating or Darwinian variations, because of the inevitable extinguishing or swamping of these extreme variations by interbreeding with the far more abundant average or modal individuals of the species."

Making such concessions, it is necessary to recognise that there are factors of evolution other than natural selection, and these require separate treatment.

CHAPTER XIII

SELECTION—SEXUAL SELECTION

In building up the theory of Natural Selection Darwin found that while this theory was sufficient to explain the useful in organic structures it did not sufficiently explain "that class of phenomena which go to constitute the Beautiful." Darwin, therefore, suggested an auxiliary theory to give a scientific explanation to these widespread phenomena. To quote Romanes: "Just as by his theory of natural selection he sought to explain the major fact of utility, so did he endeavor to explain the minor fact of beauty by a theory of what he termed Sexual Selection." Kellogg's exposition of this theory has been partly followed in the following account.

Every zoölogist is familiar with the striking differences between the male and female individual of a single species. The reader will recall the feathers of many male birds which are in striking contrast to the sober plumage of their mates. These differences in size, color, general appearances, and various specific structural details in head, trunk, wings, feet, plumage, etc., are over and beyond those primary radical differences existing in all species in which the two sexes are differentiated. Some of these differences may, however, have obvious relation to the primary differences, in that they may be connected immediately with the act of pairing or with the work of rearing the young. The presence in male insects of complexly developed holding organs, and in female mammals

of milk glands, exemplifies differences of this category. A great many sexual differences, however, have no such obvious direct relation to the function of producing and rearing the young.

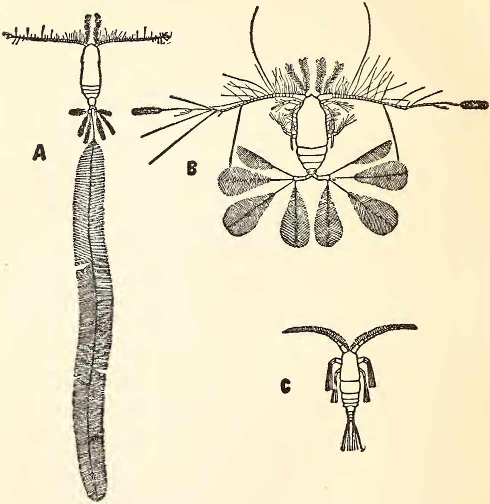


Fig. 29 —Secondary Sexual Characters in Copepods. A., male of Calocalanus plumosus; B., female of Calocalanus pavo; C., male of same species. (Morgan and Giesbrecht.)

Such are the metallic purple and bronze colors of the male grackles compared with the dull brown of the females; the long tails and brilliant coloration of the male pheasants, the great spreading, patterned tail of the peacock, the larger size or the winglessness of many female

insects, etc. All these differences between male and female of the same species of animal, beyond or in addition to the differences between the actual primary reproductive organs, are known as secondary sexual differences, or the characters themselves, which may be characteristics of physiology and habit, as well as the more familiar ones of structure, are called secondary sexual characters. The layman may not readily appreciate the abundance and the great variety of these characters, but it is a fact that almost all species of animals, excepting those in the lower invertebrate branches, show them, and if one will try to recall the aspect of the two sexes in one after another of the species of animals with which one is familiar, mammals, birds, insects, etc., one will begin to realize how widespread and significant are these secondary sexual characters.

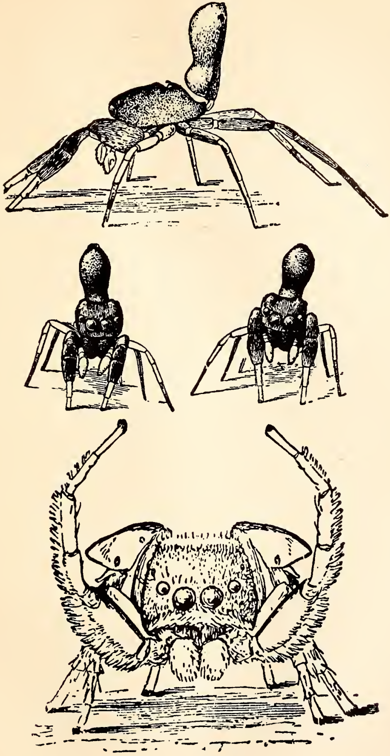
Many of these secondary sexual characters have uses which are of a kind directly helpful in the struggle for existence, as the strong antlers of the stags, useful in defense against attacking enemies; the brood sacs of the kangaroos and opossum, useful in caring for their helpless young; the milk glands and teats of all female mammals, and the protective colors and patterns of many insects and birds. But others of these secondary sexual characters are either of a kind apparently useless in the struggle for life, or even of a kind actually harmful.

Of apparent harmfulness are the conspicuous staring colors of many male birds, the long dangling plumes, the weighty crests and heavy, dragging tails of others; all these parts also usually being dangerously, conspicuously colored. The lively loud song of many male birds, and the dancing and leaping of numerous male spiders and some male birds must also involve some danger to the performers by attracting the attention of their enemies. In fact, most of those secondary sexual characters that are classified under the general head of 'exciting organs' are apparently of a sort that should be actually disadvanta-

geous in the struggle for existence. They are of a character tending to make their possessors conspicuous, and thus readily perceived by their carnivorous enemies. How is to be explained the existence of so many and such highly developed structural and physiological characters of this kind, a condition that seems to stand in direct opposition to the theory of natural selection? Darwin's answer to this question is contained in his theory of sexual selection.

This theory, in few words, is that there is practically a competition or struggle for mating, and that those males are successful in this struggle which are the strongest and best equipped for battle among themselves, or which are most acceptable, by reason of ornament or other attractiveness, to the females. In the former case, mating with a certain female depends upon overcoming in fight the other suitors, the female being the passive reward of the victor; in the second case the female is presumed to exercise a choice, this choice depending upon the attractiveness of the male. The actual fighting among males, and the winning of the females by the victor, are observed facts in the life of numerous animal species. But a special sexual selection theory is hardly necessary to explain the development of the fighting equipment—antlers, spurs, claws, etc. This fighting array of the male is simply a special phase of the already recognised intraspecific struggle; it is not a fight for room or food, but for the chance to mate. But this chance often depends on the issue of a life-and-death struggle. Natural selection would thus account for the development of the weapons for this struggle.

For the development, however, of such secondary sexual characters as ornament and song, and special odors, and 'love-dancing,' the natural selection theory can in no way account; the theory of sexual selection was the logical and necessary auxiliary theory, and when first proposed by Darwin met with quick and wide acceptance.



Characteristic 'Courting' Attitudes of Spiders.

Wallace, in particular, took up the theory and applied it to explain many cases of remarkable plumage and pattern development among birds. Later, as he analyzed more carefully his cases, and those proposed by others, he became doubtful, and finally wholly skeptical of the theory.

A few extracts from the 'Origin of Species' will present the theory in Darwin's own words. "This form of selection," he explains, "depends, not on a struggle for existence in relation to other organic beings, or to external conditions, but on a struggle between the individuals of one sex, generally the males, for the possession of the other sex. The result is not death to the unsuccessful competitor, but few or no offspring. Sexual selection is, therefore, less rigorous than natural selection. Generally, the most vigorous males, those which are best fitted for their places in nature, will leave most progeny. But in many cases victory depends not so much on general vigor as on having special weapons, confined to the male sex. A hornless stag or spurless cock would have a poor chance of leaving numerous offspring. Sexual selection, by always allowing the victor to breed, might surely give indomitable courage, length to the spur, and strength to strike in the spurred leg, in nearly the same manner as does the brutal cockfighter by the careful selection of his best cocks.

"Among birds the contest is often of a peaceful character. All those who have attended to the subject believe that there is the severest rivalry between the males of many species to attract, by singing, the females. The rock-thrush of Guiana, birds of paradise, and some others, congregate; and successive males display with the most elaborate care, and show off in the best manner, their gorgeous plumage; they likewise perform strange antics before the females, which, standing by as spectators, at last choose the most attractive partner. If man can in a short time give beauty and an elegant carriage to his

bantams, according to his standard of beauty, I can see no good reason to doubt that female birds, by selecting, during thousands of generations, the most melodious or beautiful males, according to their standard of beauty, might produce a marked effect."

Many difficulties in the way of the application of this theory have been advanced in recent years as a result of experimental work and more widespread observation. Morgan lists twenty such objections. Space will allow mention of only a few of the most important criticisms of the theory. These are outlined by Kellogg essentially as follows.

The theory can be applied only to species in which the males are markedly more numerous than the females, or in which the males are polygamous. In other cases there will be a female for each male, whether he be ornamented or not; and the unornamented males can leave as many progeny as the ornamented ones, which would prevent any cumulation of ornamental variations by selection. As a matter of fact, in a majority of animal species, at least among the vertebrates, males and females exist in approximately equal numbers.

Observation shows that in most species the female is wholly passive in the matter of pairing, accepting the first male that offers.

"Ornamental colors," moreover, as Kellogg points out, "are as often a characteristic of males of kinds of animals in which there is no real pairing as among those which pair. How explain by sexual selection the remarkable colors in the breeding season of many fishes, in which the female never, perhaps, even sees the male which fertilizes her dropped eggs?

"Choice on a basis of ornament and attractiveness implies a high degree of esthetic development on the part of the females of animals for whose development in this line we have no (other) proof. Indeed, this choice demands esthetic recognition among animals to which we

distinctly deny such a development, as the butterflies and other insects in which secondary sexual characters of color, etc., are abundant and conspicuous. Similarly with practically all invertebrate animals. Further, in those groups of higher animals where esthetic choice may be presumed possible we have repeated evidence that preferences vary with individuals. Besides, even if we may attribute fairly a certain amount of esthetic feeling to such

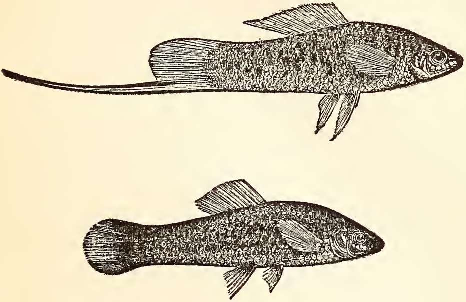


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Fig. 30 —Secondary Sexual Characters.
Callionymus eyra, male and female. (Darwin.)

animals as mammals and birds, is this feeling to be so keen as to lead the female to make choice among only slightly differing patterns of songs? Yet this assumption is necessary if the development of ornament and other attracting and exciting organs is to be explained by the selection and gradual cumulation through generations of slight fortuitously appearing fluctuating variations in the males.

"Even if the females do choose among the males on a basis of attractiveness, how are the characters of the

more attractive males to become especially fostered and accumulated by selection? Do such males produce more offspring or more vigorous ones than the other males, which, tho rejected by the first females, find their mates among the females not already mated? Are we to attribute to the more ornamental males a particular vigor? If so, may not that very vigor be the cause of the extra-production of color or plumage or wattles, etc.?

"Darwin admits, in order to explain the beginnings of color and ornament development, a certain degree of difference between the male and female in regard to their reaction to environment influences. If so, may not these admitted differences be really sufficient to account for even a pretty high degree of difference in development of secondary sexual characters?

"The special display of colors, tufts, plumes, spreading tails, and other secondary sexual characters by the males at mating time is an observed fact; the 'dances' of cranes and storks, the serenades of the song-birds, the evolutions of the male spiders, are all familiar phenomena in the mating season of these animals. And they probably do exercise an exciting effect on the females, and are probably actually displayed for this purpose. But does this in any way prove, or even give basis for, a reasonable presumption for belief in a discriminating and definitive choice among the males on the part of the female? And it is this actual choosing which is the necessary basis for the theory of sexual selection.

"How explain the well-known cases of a similar extra-development of plumage in the nuptial season by both males and females, as in certain herons and other birds? And what of those cases in which it is the female that is the brighter-colored individual of the pair? To explain the latter case Darwin assumes that in these cases the males have done the selecting, but even this rather too easy removal of the situation postulated as a fundamental generalization of the theory does not explain the first of

the questions in this paragraph. Do both sexes among the herons do selecting?"

To the objection that choice on the part of the female assumes her possession of an esthetic ideal and a power of selection in accordance with that ideal which is contrary to our knowledge of animal psychology, Lloyd Morgan answers that the choice is not one of deliberation but rather of impulse; it is simply a definite response to an adequate stimulus. "She accepts that mate which by his song or otherwise excites in sufficient degree the pairing impulse; if others fail to excite this impulse they are not accepted. It is a choice from impulse, not the result of deliberation; but it is a choice which is determined by the emotional meaning of the conscious situation. And it is the reiterated revival of the associated emotional elements which generates an impulse sufficiently strong to overcome her instinctive coyness and reluctance. It is a perceptual choice arising from impulse rather than an ideational choice due to motive and volition."

The final line of criticism is that experimental evidence is strongly opposed to the theory of sexual selection. Mayer, director of the Tortugas laboratory of the Carnegie Institute, has proved by many careful experiments that the striking differences between the wings of male and female promethea moths, 'Callosamia promethea,' are absolutely without meaning in relation to sexual selection. The animals mate normally when painted, or after the wings have been cut off and others glued on in their place. Mayer tried to test the selective action of the female. The male promethea has blackish wings, while the females are reddish-brown. In accordance with the theory of sexual selection, the peculiar coloration of the male should be due to the selection of dark-colored males, so that under this influence the males would become, in successive generations, darker until the present coloration has been attained. Mayer's own account of

his experiments and conclusions to test the preferences and selective action of the females is as follows:

"In order to test this hypothesis I cut off the wings of a number of females, leaving only short stumps, from which all the scales were carefully brushed. Male wings were then neatly glued to the stumps, and thus the female presented the appearance of a male. Under these circumstances the males mated with the female quite as readily as they would have done under normal conditions.

"I then tried the experiment of gluing female wings upon the male. Here, again, the mating seemed to occur with normal frequency, and I was unable to detect that the females displayed any unusual aversion toward their effeminate-looking consorts.

"It is also interesting to note that normal males pay no attention to males with female wings.

"In another series of experiments the wings were cut entirely off of males and females and the scales brushed off their bodies, and yet these shabby males were readily accepted by normal females; nor could I see that normal males displayed any aversion to mating with wingless females."

Mayer's next experiments were directed to the end of determining if the males found the females by sight or by smell. By enclosing females in numerous jars variously arranged, and covered or uncovered, it was readily determinable that males never pay any attention to females enclosed in transparent jars so closed as to prevent the escape of any odors from the female, while to females enclosed in boxes, or wrapped in cotton so as to be invisible, but yet capable of giving odor off into the air, males came promptly and hovered about. To locate the organs of scent in the female, Mayer cut off abdomens from various females and then placed abdomens and abdomenless females at some little distance apart. Males came to the abdomens and not to the thorax plus

wings, legs, and head parts. It was readily proved by experiments with males whose antennæ were covered with shellac, photographic paste, etc., that the sense of smell is seated in the antennæ. Males with antennæ covered with photographic paste did not find females, while the same males with this paste dissolved off did.

All this evidence showed quite clearly that it was odor rather than color which served to attract the males to the females. In lizards, too, in which sexual dimorphism is conspicuous, females showed no preference for particular patterns exhibited by the males in breeding coat. Many such experiments, with like results, seem to make the rejection of Darwin's theory of sexual selection necessary.

But if it is rejected other explanations of the origin of the secondary sexual characters are needed. Such theories have been advanced. Kellogg says of them that the theories proposed to account for secondary sexual characters "mostly rest on one or both of two principal assumptions; first, that the secondary sexual characters are produced as the result of the immediate stimulus (naturally different) of the sexually differing primary reproductive organs, this stimulus being usually considered to result from an internal secretion of the genital organs acting on certain tissues of the organism; and second, that the males, in most species, possess an excess of energy, which manifests itself in extra-growths, extra-development of pigment, plumage, etc., and that displays by the males of special movements, sound-making, etc., are direct effects or manifestations of sexual excitation."

It thus appears that the sexual selection theory, as a special application of natural selection, is far from being in good standing with present-day biologists. The truth is that most of the work recently done has been destructive, and there is, as yet, no satisfactory replacing theory.

CHAPTER XIV

FACTORS OF EVOLUTION OTHER THAN SELECTION

THE most important question raised in biological science by Darwin's work is whether natural selection has been the sole, or but the main, cause of the descent of species, or organic evolution. Darwin's own answer to this question was quite distinct. "He stoutly resisted," says Romanes, "the doctrine that natural selection was to be regarded as the only cause of organic evolution."

In many parts of his works Darwin showed that he believed in the possibility of the inheritance of the effects of the use and disuse of organs, the Lamarckian factor. This view, and also the admission of still other factors, is clearly set forth in the first paragraph of the conclusion to the 'Origin of Species.' It has been said that a more strongly worded passage cannot be found in Darwin's writings, and that the last sentences present the only note of bitterness in all the thousands of pages Darwin wrote.

"I have now recapitulated," he says, "the facts and considerations which have thoroly convinced me that species have been modified during a long course of descent. This has been effected chiefly through the natural selection of numerous successive, slight, favorable variations, aided in an important manner by the inherited effects of the use and disuse of parts, and in an unimportant manner, that is, in relation to adaptive structures, whether past or present, by the direct action of external conditions, and by variations which seem to us, in our ignorance, to

arise spontaneously. It appears that I formerly underrated the frequency and value of these latter forms of variation, as leading to permanent modifications of structure independently of natural selection.

"But as my conclusions have lately been much misrepresented, and it has been stated that I attribute the modification of species exclusively to natural selection, I may be permitted to remark that in the first edition of this work, and subsequently, I placed in a most conspicuous position—namely, at the close of the Introduction—the following words: 'I am convinced that natural selection has been the main, but not the exclusive, means of modification.' This has been of no avail. Great is the power of steady misrepresentation; but the history of science shows that, fortunately, this power does not long endure."

While Darwin thus admitted the possibility of other factors of evolution, Alfred Russell Wallace, the co-originator of the natural selection theory, has believed natural selection to be the all-sufficient factor. Romanes has thus contrasted the views of Darwin and Wallace:

According to Darwin, Natural Selection has been the main means of modification, not excepting the case of Man. (a) Therefore it is a question of evidence whether the Lamarckian factors have cooperated. (b) Neither all species, nor, a fortiori, all specific characters, have been due to natural selection. (c) Thus the principle of Utility is not of universal application, even where species are concerned. (d) Thus, also, the suggestion as to Sexual Selection, or any other supplementary cause of modification, may be entertained; and, as in the case of the Lamarckian factors, it is a question of evidence whether, or how far, they have cooperated. (e) No detriment arises to the theory of natural selection as a theory of the origin of species by entertaining the possibility, or the probability, of supplementary factors. (f) Cross-sterility in species cannot possibly be due to natural selection.

According to Wallace, Natural Selection has been the sole means of modification, excepting in the case of Man. (a) Therefore it is antecedently impossible that the Lamarckian factors can have cooperated. (b) Not only all species, but all specific characters, must necessarily have been due to natural selection. (c) Thus the principle of Utility must necessarily be of universal application, where species are concerned. (d) Thus, also, the suggestion as to Sexual Selection, or of any other supplementary cause of modification, must be ruled out; and, as in the case of the Lamarckian factors, their cooperation deemed impossible. (e) The possibility—and, a fortiori, the probability—of any supplementary factors cannot be entertained without serious detriment to the theory of natural selection, as a theory of the origin of species. (f) Cross-sterility in species is probably due to natural selection.

This comparison makes it evident that the Darwinism of Darwin is natural selection plus other factors, while the Darwinism of Wallace is natural selection alone as the cause of evolution. In late years this view of Wallace's has been highly developed by Weismann and his followers, who have argued for the all-sufficiency of natural selection, and have especially opposed other factors which Darwin admitted might have aided natural selection. This view of Wallace and Weismann should be called 'Neo-Darwinism' or 'Ultra-Darwinism.' In discussing the criticisms of natural selection it has been shown that there are serious difficulties in the way of universal application of neo-Darwinism. For this reason even Weismann has been forced to modify his views.

Most prominent of the theories of the factors of evolution which have rivaled natural selection is that put forth, before Darwin's work, by Lamarck (1744-1829). Lamarck's theory did not attract much attention during his lifetime, but since Darwin's time Lamarckism has become well known. The Lamarckian theory is commonly referred to as the theory of use and disuse and

the direct action of the environment in modifying organs. Moreover, it holds that characteristics acquired during the lifetime of an individual are transmissible by heredity.

The Lamarckian view, as given by Osborn, is formulated in the four well-known propositions following:

(1) Life, by its internal forces, tends continually to increase the volume of every body that possesses it, as well as to increase the size of all the parts of the body up to a limit which it brings about.

(2) The production of a new organ or part results from a new need or want, which continues to be felt, and from the new movement which this need initiates and causes to continue. (This is the psychical factor in his theory, which Cope later has termed Archesthetism.)

(3) The development of organs, and their force or power of action, are always in direct relation to the employment of these organs. (At another point he expands this into two sub-laws: "In every animal which has not passed the term of its development, the more frequent and sustained employment of each organ strengthens little by little this organ, develops it, increases it in size, and gives it a power proportioned to the length of its employment; whereas the constant lack of use of the same organ insensibly weakens it, deteriorates it, progressively diminishes its powers, and ends by causing it to disappear." This is now known as the Law of Use and Disuse, or Kinetogenesis.)

(4) All that has been acquired or altered in the organization of individuals during their life is preserved by generation and transmitted to new individuals which proceed from those which have undergone these changes.

The greatest weakness in the Lamarckian theory is the assumption of the inheritance of acquired characters; this Lamarck took for granted, and did not try to demonstrate. As Kellogg has well said:

"That an animal in its lifetime, and especially during its immature life, can effect very considerable changes

in some of its body-parts by special use or disuse of these parts, or that certain parts may be modified through the influence of external stimuli, is familiar knowledge. The heart and lungs can be enlarged by special use; in short, almost any of the organs of the body which are actively used can be modified either by unusual or extra use, or by unusual lack of use. Now this use is, in Nature, almost always of the character of a better aiding in successful living; that is, it is adaptive use. If such betterment of organs and their functions acquired by individuals could be inherited by their young, it is obvious that general adaptations of this sort could be rapidly developed in the course of generations, and new species, new, that is, because of the adaptive changes thus effected, be formed. This is the essential thought in Lamarck's theory of the method of adaptation and species-forming.

"The essential principle of Lamarckism is an orthogenetic evolutionary progress toward better and finer adaptation and adjustment resulting from the inherited effects of actual use, disuse, and functional stimulation of parts. It is a great thought and a clear one, and only needs the proof of the actuality of the inheritance of individually acquired characters to make it one of the principal causal explanations of adaptation and species change.

"However, it is exactly this proof that is wanting. At any rate, proof of the character and extent necessary to convince all or even a majority of biologists is wanting. The examples or cases brought forward by Lamarckians of the alleged inheritance of mutilations, of the results of disease, and of use and disuse, are not convincing. It is one of Weismann's positive contributions to biology to have analyzed case after case of alleged inheritance of acquired characters and shown its falseness, or at least uncertainty. Many of these cases he has been able to explain as a result of selection; others remain inexplicable; a few only are insisted on by the Lamarckian,

champions as indisputable examples of such inheritance. But this very paucity of so-called proved cases, where there should be thousands of obvious examples if the principle were really sound, is argument against Lamarckism.

"Our knowledge, too, of the mechanism of heredity makes strongly against the theory of the inheritance of acquired characters. Another of Weismann's positive contributions to biology is his generally sound distinction between the germ-plasm and the soma-plasm and parts of the many-celled body. At maturity the animal body is composed of a small mass of germ-plasm (germ-cells), situated in the ovaries or testes, and a great mass of somatic tissues and organs, all the rest of the body, in fact. Now, what is the condition that exists in the body after a somatic part is modified by use or disuse or by other functional stimulus, as when a muscle is enlarged by exercise, the sole of the foot calloused by going barefoot, an ear more finely attuned by training? We have a definite physical change in a definite organ, but is the germ-plasm in any way changed or affected by this superficial or specific somatic modification, or, if changed, is it changed so that it will produce in its future development a similar change in the same organ of the future new individual? What possible mechanism have we in the body to produce or insure such an effect on the germ-plasm? The answer is obvious and flat; we certainly know of no such mechanism; in fact, what we do know of the relation of the germ-cells to the rest of the body makes any satisfactory conception of such a mechanism as yet impossible.

"But even were the inheritance of acquired characters now an established fact, or if it should come to be one, it must be kept in mind that Lamarckism could be substituted only partly for Darwinism. There are many adaptations and much species-forming that Lamarckism

might explain, but also there are hosts of adaptations that Lamarckism cannot explain."

A number of American biologists have added to the principles of Lamarck that of natural selection. Without denying to natural selection a more or less important part in the process of organic evolution, members of this school believe that much greater importance ought to be assigned to the inherited effects of use and disuse than was assigned to these agencies by Darwin. It is obvious that neo-Lamarckism has to face the problem of the heredity of acquired characters—this is the fundamental and as yet unproved proposition of the theory.

The Darwinian theory is based upon variations which occur in all directions, unfavorable as well as favorable, and hence are known as indeterminate variations. Definite lines of development are produced from these chance variations by the elimination in the struggle for existence of all other lines; that is, natural selection permits only certain kinds of variation to persist and to accumulate. According to this theory the persistence of the useful is explained, but there are certain phenomena which cannot so easily be explained. Among these may be mentioned development along definite lines which are not advantageous and over-development of parts to a harmful degree. Moreover, there is difficulty in explaining the beginnings of advantageous modifications from fluctuating individual variations. It is to explain these phenomena that the theory of 'Orthogenesis' has been developed.

According to the theory of orthogenesis variations are predetermined and hence development is fixed along definite lines. There are various views as to the origin of these predetermined variations. The Lamarckians would base them on the perpetuation and accumulation of the effects of use and disuse, etc.; Roux would explain them on the battle of the parts theory and Weismann on the germinal selection theory, referred to later in this chapter.

Many phases of the theory of orthogenesis have been

advanced by Nägeli, Eimer, Cope and others. Some of these go so far as to say that orthogenesis takes the place of natural selection. Nägeli belongs to this school, and he "believes that animals and plants would have developed about as they have even had no struggle for existence taken place and the climate and geologic conditions and changes been quite different from what they actually have been," says Kellogg.

Others hold that orthogenesis is an adjunct of natural selection. Prominent among the latter is Professor Whitman, of Chicago, who sees no fundamental contradictions between the theories and who believes that orthogenesis and natural selection are factors of evolution working together at times; in other words, determinate orthogenetic variations are preserved by natural selection —a conclusion which appeals to many biologists as most reasonable.

Associated with the name of de Vries, the Amsterdam botanist, is the Mutation Theory, or Heterogenesis. But this general conception of species-forming on a basis of the occurrence of occasional, sudden, fixed and often considerable changes or variations in the offspring of a plant or animal is a conception not of course new with de Vries, but one variously expressed by numerous biologists from Darwin's time on, especially by von Kölliker, Galton, Dall, Bateson, Emery, Scott and Korschinsky. It is, however, chiefly due to the patient, persistent, well-planned and extensive experiments and observations of de Vries that this theory of species-forming by heterogenesis, or as called by de Vries, by mutations, has recently received so much renewed attention.

"The meaning of heterogenesis," says Kellogg, "in connection with species-forming and descent is essentially this: Whereas by the Darwinian theory species are transformed slowly and by slight changes in at first one or two or a few and only later in more parts, and all new species are derived from the old ones (which usually disappear as

the new ones appear) by the gradual selection of the advantageous ones among the regular slight, fluctuating, individual variations (known commonly as Darwinian variations and which mostly occur according to the law of error), by the theory of heterogenesis new species appear suddenly, not by a selective choosing among the slight, fluctuating Darwinian variations, but independently of selection and largely independently of the so-called Darwinian variations by the appearance in fixed definite form of several to many slight to considerable variations, which give the new species definite characteristics differentiating it often in many particulars from the old species, which differentiating characteristics are fully and faithfully transmitted to the succeeding generations of individuals derived from this suddenly born new species."

Extensive observations and experimentation to test the mutation theory are now in progress, and it is too early to form a final opinion as to its bearing on the theory of natural selection. It has been warmly welcomed, but even its friends admit that it needs the support of more experiments and more facts. T. H. Morgan sums up the advantages of the theory as follows: "Since the mutations appear fully formed from the beginning, there is no difficulty in accounting for the incipient stages in the development of an organ, and since the organ may persist, even when it has no value to the race, it may become further developed by later mutations and may come to have finally an important relation to the life of the individual.

"The new mutations may appear in large numbers, and of the different kinds, those will persist that can get a foothold. On account of the large number of times that the same mutations appear, the danger of becoming swamped through crossing with the original form will be lessened in proportion to the number of new individuals that arise.

"If the time of reaching maturity in the new form is different from that in the parent forms, then the new species will be kept from crossing with the parent form,

and since this new character will be present from the beginning, the new form will have much better chances of surviving than if a difference in time of reaching maturity had to be gradually acquired.

"The new species that appear may be in some cases already adapted to live in a different environment from that occupied by the parent form, and if so, it will be isolated from the beginning, which will be an advantage in avoiding the bad effects of intercrossing.

"It is well known that the differences between related species consist largely in differences of unimportant organs, and this is in harmony with the mutation theory, but one of the real difficulties of the selection theory.

"Useless or even slightly injurious characters may appear as mutations, and if they do not seriously affect the perpetuation of the race, they may persist."

Still another causal factor of the descent of species is to be found in the isolation theories differently expressed by various authors.

Altho to many biologists isolation alone is sufficient to account for the origin of species, most evolutionists consider it to be a very widespread and effective auxiliary theory to natural selection. Selection needs help from just such a factor. Just what is meant by this theory in its different phases Kellogg describes as follows:

"If, in a species, a number of individuals show a certain congenital variation, this variation will probably be lost by cross-breeding with individuals not having it, unless the individuals having it are in the majority or unless they become in some way isolated from the others and segregated so that they will breed among themselves. By such isolation and such in-and-in breeding the newly appearing congenital variations might soon become established, and if advantageous be so considerably developed as soon to distinguish as a variety or incipient species the members of the isolated colony. With time a distinct new species

might result. Are there means to produce such isolation of groups of individuals belonging to a common species?

"The answer to this is certainly an affirmative one. There seem to be, indeed, several means of producing isolation, and the isolation may be variously named accordingly. Undoubtedly the most important of these kinds of isolation, at least in the light of our present knowledge, is that known as geographical or topographical isolation. Isolation produced in other ways may be called biologic or physiologic or sexual isolation. In the case of geographic or topographic isolation the isolated group or groups of individuals are actually in another region or locality from the rest of the species, this being the result of migration, voluntary or involuntary.

"In biologic isolation the individuals of the species all inhabit the same territory, but become separated into groups by structural or physiological characters which prevent miscellaneous inter-breeding. The real founder and most insistent upholder of the theory of species-forming by isolation (geographic and topographic isolation) was Moritz Wagner (1813-1887), a traveler and naturalist, whose wanderings and observations brought to him the conviction that while natural selection might modify species and even produce continuous evolution it could never differentiate species, that is, produce new species."

In support of isolation theories, it is argued by biologists that isolation is very important as one factor in forming species. It is, however, obvious that isolation in itself cannot be the basic and all-sufficient cause for the production of specific differentiation, any more than any selective factor can. The prerequisite in both cases is the occurrence of variation. What are the variations and how are they produced? These are the fundamental questions in species-forming. Isolation is a tremendously favoring condition, but not a primary cause of species-forming. It

tends to help along, to hurry up species disintegration, not to initiate it.

The Germinal Selection Theory advanced by Weismann attempts to explain the origin of variations. According to Weismann's neo-Darwinism, only congenital variations, those present at birth, are transmissible by heredity. In brief, the theory holds that the germ-plasm may be influenced by conditions under which an organism lives and may 'acquire' variations in a determinate or favorable direction. Knowing this factor, "we remove, it seems to me," writes Weismann, "the patent contradiction of the assumption that the general fitness of organisms or the adaptations necessary to their existence are produced by accidental variations—a contradiction which formed a serious stumbling-block to the theory of selection. Tho still assuming that primary variations are 'accidental,' I yet hope to have demonstrated that an interior mechanism exists which compels them to go on increasing in a definite direction the moment selection intervenes. Definitely directed variation exists, but not predestined variation running on independently of the life conditions of the organism as Nägeli, to mention the position that the most extreme advocate of this doctrine has assumed; on the contrary, the variation is such as is elicited and controlled by those conditions themselves, tho indirectly."

There are numerous minor theories proposed to explain difficulties in the more general theories. For these the reader is referred to special books like Kellogg's 'Darwinism To-day,' Jordan and Kellogg's 'Evolution and Animal Life' and Morgan's 'Evolution and Adaptation.'

Most biologists at present seem inclined to look for truth in a combination of the several theories. Thus Whitman says: "Natural selection, orthogenesis and mutation appear to present fundamental contradictions, but I believe that each stands for truth, and reconciliation is not distant. The so-called mutations of 'Oenothera' are indubitable facts, but two leading questions remain to be answered.

First, are these mutations now appearing, as is agreed, independently of variation, nevertheless a production of variations that took place at an earlier period in the history of these plants? Secondly, if species can spring into existence at a single leap, without the assistance of cumulative variations, may they not also originate with such assistance? That variation does issue a new species, and that natural selection is a factor, tho not the only factor, in determining results, is, in my opinion, as certain as that grass grows altho we cannot see it grow. Furthermore, I believe I have found indubitable evidence of species-forming variation advancing in a definite direction (orthogenesis) and likewise of variations in various directions (amphigenesis). If I am not mistaken in this, the reconciliation for natural selection and orthogenesis is at hand."

Others, like H. F. Osborn, think that there are still some unknown factors of evolution. In a lecture entitled 'The Unknown Factors of Evolution' Osborn says: "The general conclusion we reach from a survey of the whole field is, that for Buffon's and Lamarck's factors we have no theory of heredity, while the original Darwin factor, or neo-Darwinism, offers an inadequate explanation of evolution. If acquired variations are transmitted, there must be, therefore, some unknown principle in heredity; if they are not transmitted, there must be some unknown factor in evolution."

The present plight seems to be that species-forming and evolution are not susceptible of explanation without the help of some Lamarckian factor; and, on the other hand, the actuality of any such factor in the light of our present knowledge of heredity cannot be assumed. The discovery of the 'unknown factors of evolution' is therefore one of the most important quests of present-day biologic research.

CHAPTER XV

HEREDITY

No topic in all biology has received so much attention in recent times, both from investigators and from the intelligent public at large, as Heredity. The reason for this interest is to be found in the importance of heredity for the individual human life, its practical importance in breeding plants and animals and its bearing on the evolutionary theory of biology. Its importance in these lines is clearly related by J. Arthur Thomson, of Aberdeen, in his recent book, 'Heredity': "There are no scientific problems of greater human interest than those of Heredity," he declares, "that is to say, the genetic relation between successive generations. Since the issues of the individual life are in great part determined by what the living creature is or has to start with, in virtue of its hereditary relation to parents and ancestors, we cannot disregard the facts of heredity in our interpretation of the past, our conduct in the present or our forecasting of the future. Great importance undoubtedly attaches to Environment in the widest sense—food, climate, housing, scenery and the animate 'milieu'; and to Function in the widest sense,—exercise, education, occupation or the lack of these; but all these potent influences act upon an organism whose fundamental nature is determined, tho not rigidly fixed, by its Heredity, that is, we repeat, by its genetic relation to its forebears. As Herbert Spencer said, 'Inherited constitution must ever be the chief factor in determining

character.' And what is important in regard to Man's heredity is even more demonstrably important in regard to his domesticated animals and cultivated plants. What has been achieved in the past in regard to horses and cattle, pigeons and poultry, cereals and chrysanthemums, by experimental cleverness and infinite patience may be surpassed in the future if breeders and cultivators can attain to a better understanding of the more or less obscure laws of inheritance on which all their results depend.

"The study of heredity is also of fundamental importance in the domain of pure science, in the biologist's attempt to interpret the process of evolution by which the complexities of our present-day fauna and flora have gradually arisen from simpler antecedents. For heredity is obviously one of the conditions of evolution, of continuance as well as of progress. There would have been heredity even if there had been a monotonous world of Protists without any evolution at all, but there could not have been any evolution in the animate world without heredity as one of its conditions. The study of heredity is inextricably bound up with the problems of development, reproduction, fertilization, variation and so on; in short, it is one of the central themes of Biology."

Some outline of the reproduction of organisms is a necessary prelude to a discussion of the theories of heredity. It has been stated that as a rule individual plants and animale start as a single cell. In the one-celled organisms the simple division of the parent cell into daughter cells constitutes reproduction. Each of the daughter cells thus formed is a young organism with the power to grow to mature size, divide and complete a life-cycle by reproducing. One unicellular organism to-day may merge its individuality into two offspring in a few hours and then into four in the next few hours and so on.

Many-celled plants and animals begin their individual existence as one-celled ova or ovules which by oft-repeated cell-division produce the thousands of cells found

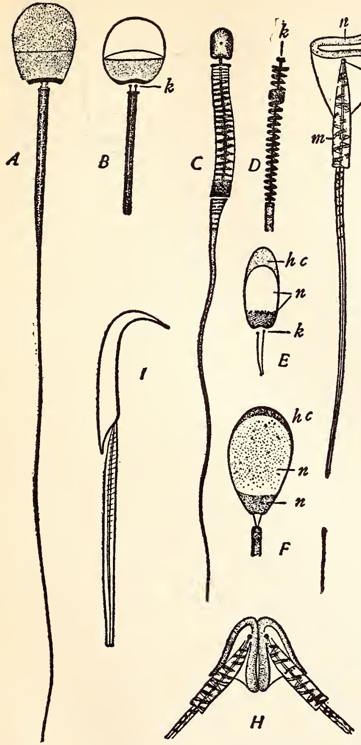


Fig. 31 —SPERMATOZOA OF VARIOUS MAMMALS.

A., badger (living); B., same after staining; C., bat; D., same, flagellum and middle-piece; E., same, head only; F., pig, head only; G., opossum; H., double sperm alozo from bat; I., rat. (h. c., head-cap; k., end-knob; m., middle piece; n., nucleus.) (Wilson.)

in the body of the larger plants and animals. In these, certain cells are set apart as reproductive cells for the development of new individuals.

As is well known, most higher plants and animals have differentiated into male and female sexes. Each produces a peculiar kind of reproductive or germ cell. In animals the organs of the male known as spermaries produce minute cells (sperm-cells or spermatozoa), provided with a vibratile appendage capable of causing swimming in fluids. The organs of the female known as ovaries produce ova or eggs. These eggs are simple cells, usually incapable of division without fertilization. By swimming a sperm-cell comes into contact with an egg-cell, penetrates and is transformed into a nucleus which moves to meet and fuse with the female nucleus of the egg-cell. This entrance and fusion of sperm-nucleus with egg-nucleus is fertilization. Immediately after the fusion the fertilized egg or oosperm shows signs of preparation for division by mitosis and soon the two-cell stage is formed. In like manner by mitosis cleavage again takes place in each of these two cells and there follow stages of four, eight, sixteen, thirty-two, etc., cells until the egg has been divided into a mass of cells. Cell-division continues, differentiation into tissues takes place and a folding off of organs goes on until the individual is completely formed.

In plants the process is in essentials the same. In the lower plants, even including the mosses and the ferns, the male germ-cells are motile and swim to meet the female germ-cells. They enter and produce changes similar to those described for animals. In the higher flowering plants motile male-cells are not found. Instead there are pollen grains adapted to being carried by winds, insects, etc., from the anther of one flower to the pistil of another. From the pollen grain a delicate tube grows down into the ovary and into contact with the egg-cell or ovule of the plant. Down this tube moves a small cell from the inside of the pollen grain. Its nucleus fuses with the egg-

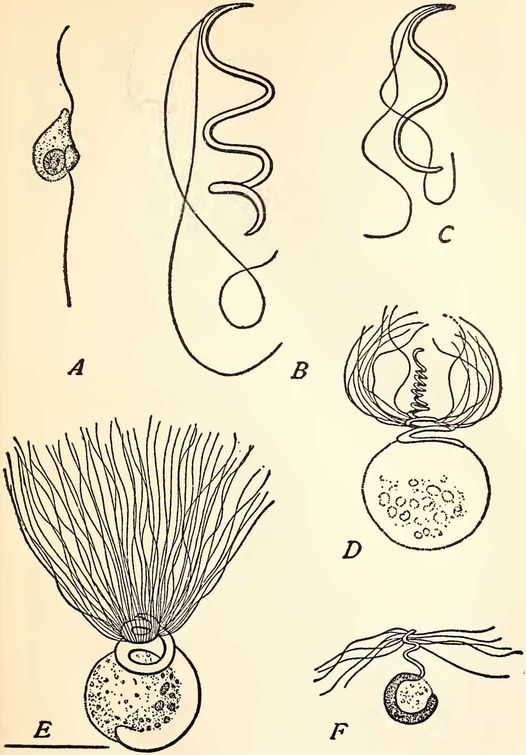


Fig. 32 —SPERMATOZOIDS OF PLANTS.
A., Fucus analga; B., Pellia, a liverwort; C., Sphagnum, a moss; D., Marsilia; E., Angiopteris, a fern; F., Phegopteris, a fern. (Wilson.)

nucleus, producing fertilization and leading soon to cell-division.

In brief outline, the above is the story of the usual origin of higher plants and animals in sexual reproduction. The essential point is that new individuals arise from two cells, one derived from each parent.

Exceptional cases do occur. Some multicellular animals like Hydra and certain worms may give rise to buds or divide into two or more new animals. This is similar to

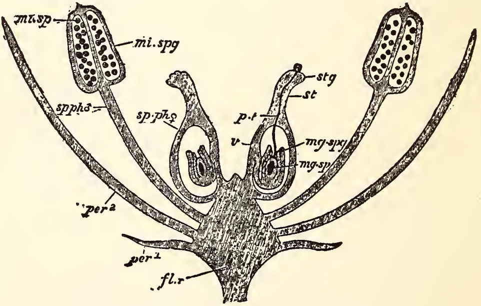


Fig. 33 —Fertilization in the Plant.

sp. ph., sporophylls or stamens; mg. sp., megaspore; mi. spg., microsporangia; per., petals; per., sepals; fl. 2., receptacle; sp. ph., carpel; stg., stigma; st., style; mg. spg., megasporangia; mg. sp., megaspore; p. t., pollen tube. (Parker.)

the power of many plants to reproduce from buds, shoots or cuttings. This process is known as asexual reproduction, in which also is classed the simple division of one-celled plants and animals. In most cases organisms with the power of asexual reproduction also multiply by sexual reproduction, but many plants seem to be able to multiply indefinitely by runners, tubers and so on.

Another exception to the general rule that higher indi-

viduals develop from the fusion of two germ-cells is found among certain species of plant lice (Aphides), water fleas (small crustacea) and others which under certain conditions develop from unfertilized eggs. This is parthenogenesis. With the possible exception of certain scale insects, parthenogenesis among animals is always temporary and parthenogenetic generations are from time to time, usually in the fall, succeeded by a generation reproducing sexually. Among plants many species are believed to be permanently parthenogenetic.

When such cases are considered, it must be admitted that the vital processes may continue indefinitely simply by repeated division of the cells themselves, without the intervention of the act of fertilization; still, on the other hand, it is necessary to conclude, on account of the wide distribution throughout the whole organic kingdom of the phenomenon of fertilization, that this institution is of essential importance among the vital processes and that it is fundamentally connected with the life of the cell.

For an understanding of the problems of heredity the method of development, of sperms, 'spermatogenesis,' and of ova, 'oogenesis,' is necessary as well as the exact steps of the process by which an oosperm or unicellular embryo is formed by the union of the two sexual elements. In plants and animals both ovary and spermary are at first composed of cells of the ordinary kind, the primitive sex-cells, and it is only by the further development of these that the sex of the gonad is determined.

In the spermary the sex-cells undergo repeated fission, forming what are known as the sperm-mother-cells, in which the number of chromosomes is constant in any given species. The sperm-mother-cell divides and the process of division is immediately repeated, the result being that each sperm-mother-cell gives rise to a group of four cells having half the normal number of chromosomes, the four cells so produced being the immature sperms. Thus the sperm or male gamete is a true cell, and is specially modi-

fied in most cases for active movements. This mitotic division by which the number of chromosomes in the sperm-mother-cells is reduced by one-half is known as a reducing division.

As already stated, the ova also arise from primitive sex-cells. These divide and give rise to the egg-mother-cells. The egg-mother-cells do not immediately undergo division, but remain passive and increase, often enormously, in size, by the absorption of nutriment from surrounding parts; in this way each egg-mother-cell becomes an ovum. In addition to increase in the bulk of the protoplasm itself, a formation of plastic products usually goes on to an immense extent and the ovum may attain a comparatively enormous size, as, for instance, in birds, in which the 'yolk' is simply an immense egg-cell.

Such an ovum is incapable of being fertilized or of developing into an embryo; before it is ripe for conjugation with a sperm or able to undergo the first stages of segmentation it has to go through a process known as the maturation of the egg. Maturation consists essentially in a twice-repeated process of cell-division by mitosis, and by its means two small cells called polar cells are thrown off. The ovum has now lost a portion of its protoplasm, together with three-fourths of its chromatin, half having passed into the first polar cell and half of what remained into the second: the remaining one-fourth of the chromatin takes on a rounded form and is distinguished as the female pronucleus. The formation of both polar cells takes place by a reducing division, so that while the immature ovum contains the number of chromosomes found in the ordinary cells of the species, the mature ovum, like the sperm, contains only one-half the normal number.

Shortly after, or in some cases before maturation, the ovum is fertilized by the conjugation with it of a single sperm. Sperms are produced in vastly greater numbers than ova, and it often happens that a single egg is seen quite surrounded with sperms, all apparently about to con-

jugate with it. It has, however, been found to be a general rule that only one of these actually conjugates; the others, like the drones in a beehive, perish without fulfilling the one function they are fitted to perform.

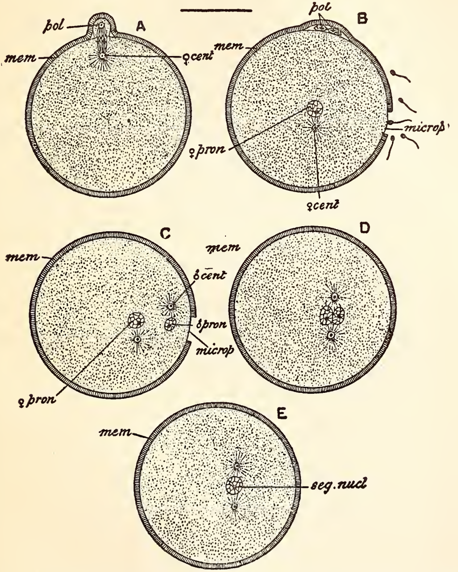


Fig. 34 —Maturation and Impregnation of Animal Ovum. Memb., cell membrane; cent., female centrosome; pol., polar cell; microp., micropyle; spermatozoids are seen near micropole and female pronucleus; cent., male centrosome; pron., male pronucleus; seg. nucl., segmentation nucleus. (Parker and Parker.)

The sperm and egg nuclei approach one another and finally unite to form what is called the segmentation nucleus, the single nucleus of what is not now the ovum, but the oosperm —the impregnated egg or unicellular embryo. The fertilizing process is thus seen to consist of the union of two nuclear bodies, one contributed by the male gamete or sperm, the other by the female gamete or ovum. It follows from this that the essential nuclear matter or chromatin of the oosperm is derived in equal proportions from each of the two parents. Moreover, as both male and female pronuclei contain only half the number of chromosomes found in the ordinary cells of the species, the union of the pronuclei results in the restoration of the normal number to the oosperm.

Fertilization being thus effected, the process of segmentation, or division of the oosperm, takes place as described. The significance of these observed phenomena of maturation, fertilization and cell-division in modern theories of inheritance will be apparent.

The main facts of organic reproduction which are fundamental to a consideration of the modern problems of heredity having been outlined, a brief survey of some of the most prominent theories of heredity which have been advanced during the last two centuries will be given, after which attention will be directed to the present-day problems of heredity, including 'Mendelism,' or the experimental study of heredity, and those cytological problems which have as their aim the identification of the inheritance material in the germ-cells.

It is not strange that of the many attempts at theories of heredity the early ones were essentially mystical and fell back on the supernatural to explain what could not be seen. Throughout the seventeenth and eighteenth centuries there prevailed a theory of preformation. The believers in this theory, men like Bonnet and Haller, maintained the preformations of the organism and all its parts within the egg. They regarded the apparent new forma-

tion of organs during development as an illusion, and held that development was merely an unfolding of this preformed miniature. Moreover, they believed that the germ contained not only a preformation of the organism into which it was to grow, but of successive generations as well. To quote from Thomson: "Preformed miniature lay within preformed miniature in ever-increasing minute-

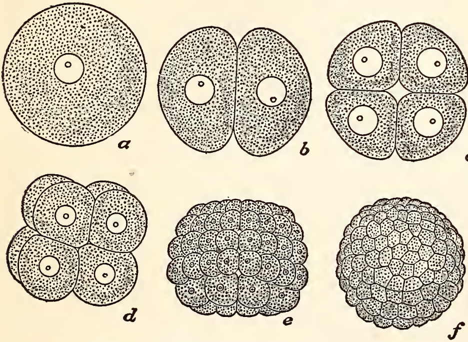


Fig. 35 —SEGMENTATION OF AN OVUM.
Showing two, four, eight-cell and later stages. (Sedgwick and Wilson.)

ness, as if in a conjurer's box. Thus it was computed that Mother Eve must have included over 200,000 millions of homunculi, or sometimes it was Adam who was made to bear this burden. For according to one party, the ovists—*e.g.,* Malpighi—it was the ovum that contained the miniature which had to be unfolded; while according to others—the animalculists—it was the sperm which contained the preformed model." But how the germ came to have this preformed model they could not tell.

Caspar Friedrich Wolff was the first to raise a strong protest against the speculations of the preformationists and to advance a new theory. Appealing to facts, he showed that in the early stages of the chick's development there was no visible hint of a preformed miniature, but that various organs made their appearance successively and gradually and were to be seen being formed. He held that there is a new formation, or 'epigenesis.' But how the germ that seems to start anew every time can develop as it does the upholders of the theory of epigenesis could not tell. For their ultimate explanations of heredity both schools fell back on the assumption of hyperphysical agencies as the earlier theorists had done before them.

Passing from these mystical interpretations of the phenomena of heredity, there are a whole series of theories which are in varying degrees scientific and may be fairly described by the general designation pangenetic. Thomson in 'The Science of Life' and in 'Heredity' gives good accounts of the various theories of heredity. From these works the material in this section has been taken. These theories all have this in common, that they seek to explain the uniqueness of the germ-cell by regarding it as a center of contributions from different parts of the organism—a collection of samples from the various organs. Spencer, Darwin, Jäger, Galton, Brooks and others at one time or another contributed toward these theories.

In 1864 Spencer suggested the existence of 'physiological units' derived from and capable of development into cells, and supposed that they accumulated in the germ-cells, which thus became in a conceivable sense miniature organisms. The best-known theory of this class is the 'provisional hypothesis of pangenesis' enunciated by Darwin in 1868. The main suggestions of this theory are as follows:

Every cell of the body, not too highly differentiated, throws off characteristic gemmules;

These multiply by fission, retaining their characteristics;

They become specially concentrated in the reproductive elements in both sexes;

In development the gemmules unite with others like themselves, and grow into cells like those from which they were originally given off, or they remain latent during development through several generations.

By means of this theory Darwin attempted to explain not only the simpler facts of heredity, but also "those very curious but abundant cases in which a character is transmitted in a latent form and at last reappears after many generations, such cases being known as 'atavism,' or 'reversion'; and again, those cases of latent transmission in which characteristics special to the male are transmitted to the male offspring through the female parent without being manifest in her; and yet again, the appearance at a particular period of life of characters inherited and remaining latent in the young organism," as Lankester expresses it.

The great defect of this theory is obviously its entirely hypothetical character—no one has ever observed any gemmules. Moreover, it is not in harmony with the results of experiments—*e.g.*, on transfusion of blood—or with what is known of the physiology of cells or with the facts of experimental inheritance.

The next theory to be noted is the theory of Genetic or Germinal Continuity. This theory was first suggested by Owen in 1849. Since then Häckel, Jäger, Brooks, Galton, Nussbaum, Weismann, and a score of others have contributed toward it.

In its earlier conception this germinal continuity consisted in a continuity of germ-cells. A summary of this idea follows.

At an early stage in the embryo, the future reproductive cells of the organism are often distinguishable from those which are forming the body.

The latter develop in manifold variety and lose almost all likeness to the mother germ.

The former—the reproductive rudiments—are not implicated in the differentiation of the 'body,' remain virtually unchanged, and continue the protoplasmic tradition unaltered.

As the sex-cells of the offspring are thus continuous with the parental sex-cells which give rise to it, they will in turn develop into similar organisms.

In this view the reproductive cells form a continuous chain and the reproduction of like by like is natural and necessary. But a serious difficulty besets this doctrine, for a direct chain of cellular continuity can only be said to exist in a few cases. Thus this theory of the continuity of the germ-cells has been replaced by the newer theory of the continuity of the germ-plasm.

This is Weismann's theory. Weismann has worked it out in the minutest details. The problems which he discusses are too intricate and technical for any but a special student. For present purposes a very brief summary as expressed by Thomson will be sufficient.

"A living creature usually takes its origin from a fertilized egg-cell, from a union of an ovum and a spermatozoon. These germ-cells are descended by a continuous cell-division from the fertliized ova which gave rise to the two parents; they have retained the organization of the fertilized ova, and this organization has its vehicle in the chromatin of the nucleus—the germ-plasm. This germ-plasm consists of several chromosomes or idants, each of which is made up of several pieces or ids, each of which (here hypothesis begins) is supposed to contain all the potentialities—generic, specific, and individual—of a new organism. Each id is a microcosm with an architecture which has been elaborated for ages; it is supposed to consist of numerous determinants, one for each part of the organism that is capable of varying independently or of being independently expressed during development.

Lastly, each determinant is pictured as consisting of a number of ultimate vital particles of biophores, which are eventually liberated in the cytoplasm of the various embryonic cells. All these units of various grades are capable of growth and of multiplication by division."

In its more general aspects this view of Weismann's represents what might be called the dominant modern view. That is, there is general belief that the germ-cell inherits from the parental germ-cells an organization of great complexity, including an intricate architecture of minute particles which are the material bearers of particular inheritance qualities. Not all biologists, however, agree with Weismann in his limitation of the inheritance material to the chromosomes. It is here that the inheritance problems of to-day have their beginning.

Much attention has in recent years been given to the experimental study of variation and heredity. These experiments are of interest in connection with Mendel's law, a law so important in the science of biology that Professor Bateson has written of it, "The experiments which led to this advance in knowledge are worthy to rank with those that laid the foundation of the atomic laws of chemistry." The discoverer of this law was Gregor Johann Mendel (1822-1884), an Augustinian monk. He was a man of varied interests, and in his gardens performed many hybridization experiments on plants. In 1866 he published a paper giving the results of his experiments, entitled 'Experiments in Plant Hybridization.' This paper did not attract much attention at the time, probably because of the enthusiasm and the controversy evoked by the natural selection theory, and lay practically unknown in the Proceedings of the Natural History Society of Brünn for over thirty years. A revival of interest in the experimental study of variation and heredity at about the beginning of the present century led to the rediscovery of the Mendelian principles of heredity by several botanists working separately, and about that time Bateson

brought into prominence Mendel's work and by a long series of experiments confirmed and extended it.

To gain an idea of the scope of these principles one cannot do better than turn to Mendel's own account of his experiments. Punnett's 'Mendelism' and Thomson's 'Heredity' give such an account, and from these sources the following statements have largely been taken.

In the selection of a plant for experiment Mendel recognised that two conditions must be fulfilled. In the first place, the plant must possess differentiating characters, and secondly, the hybrids must be protected from the influence of foreign pollen during the flowering period. In the edible pea Mendel found an almost ideal plant to work with. The separate flowers are self-fertilizing, while complications from insect-interference are practically non-existent. As is well known, there are numerous varieties of the eating-pea exhibiting characters to which they breed true. In some varieties the seed color is yellow, while in others it is green. In some varieties the seeds are round and smooth when ripe; in others they are wrinkled. Some peas have purple, others have pure white flowers. Some peas again, when grown under ordinary conditions, attain to a height of 6 to 7 feet, while others are dwarfs which do not exceed 1½ to 2 feet.

Mendel selected a certain number of such differentiating characters and investigated their inheritance separately for each character. Thus in one series of experiments he concentrated his attention on the heights of the plants. Crosses were made between tall and dwarf varieties, which previous experience had shown to come true to type with regard to these characters. It mattered not which was the pollen-producing and which the seed-bearing plant. In every case the result was the same. Tall plants resulted from the cross. For this reason Mendel applied the terms 'Dominant' (D) and 'Recessive' (R) to the tall and dwarf habits respectively.

In the next generation the cross-bred plants (products

of D and R or R and D, but all apparently like D) were allowed to fertilize themselves, with the result that their offspring exhibited the two original forms, on the average three dominants to one recessive. Out of 1,064 plants, 787 were tall, 277 were dwarfs.

When these recessive dwarfs were allowed to fertilize themselves they gave rise to recessive dwarfs only for any number of generations. The recessive character bred true.

When the dominants, on the other hand, were allowed

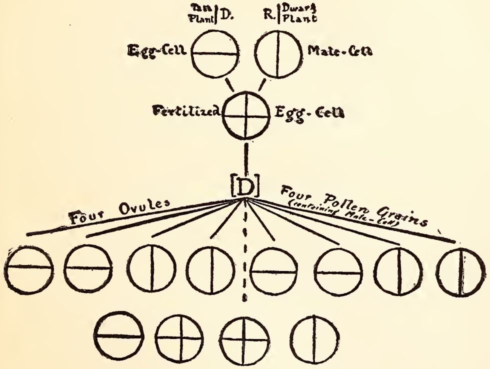


Fig. 37 —SEGREGATION OF GERM-CELLS.

D., dominant parent; R., recess of parent. The fertilized egg-cell, showing both qualities, "tallness" (1) and "dwarfness" (2), develops into an "impure" dominant. Suppose this plant to produce 4 egg-cells and 4 male-cells. The mature egg-cells consist of 2 sets—2 with potential quality of "tallness," 2 with potential quality of "dwarfness." The mature male-cells also consist of 2 sets—2 with the potential quality of "tallness," 2 with the potential quality of "dwarfness." What are the chances of fertilization? The result must be as indicated. In other words, D. — 2 (D.) — R.

to fertilize themselves, they produced one-third of 'pure' dominants (producing dominants only when self-fertilized) and two-thirds of cross-bred dominants, which on self-fertilization again gave rise to a mixture of dominants and recessives in the proportion of 3: 1.

If in an experiment with mice a gray house-mouse is crossed with a white mouse, the offspring are all gray. Grayness is dominant; albinism is recessive. The gray hybrids are inbred; their offspring are gray and white in the proportion 3: 1. If these whites are inbred they show themselves 'pure,' for they produce whites only for subsequent generations. But when the grays are inbred they show themselves of two kinds, for one-third of them produce only grays, which go on producing grays; while the other two-thirds, apparently the same, produce both grays and whites. And so it goes on.

In his exceedingly clear exposition of Mendelism (1905) R. C. Punnett states the result thus: "Wherever there occurs a pair of differentiating characters, of which one is dominant to the other, three possibilities exist: there are recessives which always breed true to the recessive character; there are dominants which breed true to the dominant character, and are therefore pure; and thirdly, there are dominants which may be called impure, and which on self-fertilization (or inbreeding, where the sexes are separate) give both dominant and recessive forms in the fixed proportion of three of the former to one of the latter."

To explain such phenomena Mendel suggested that the hybrid produces in equal numbers two kinds of germ-cells (two kinds of egg-cells or two kinds of pollen-grains)—that there is is in the developing reproductive organ a segregation of germ-cells into two equal camps, one camp with the potential quality of tallness, the other camp with the potential quality of dwarfness. Thus, if there are six ovules, three contain in their egg-cell the primary constituent corresponding to tallness, and three contain the

primary constituent corresponding to dwarfness. Each of these is pollinated by a pollen-grain, which, by hypothesis, contains the potential quality of tallness or of dwarfness; and if the two kinds of pollen-grains are present in equal numbers, each ovule has an equal chance of being fertilized by a pollen-grain with a potential quality of tallness or by a pollen-grain with a potential quality of dwarfness. Therefore the result must be a set of off-

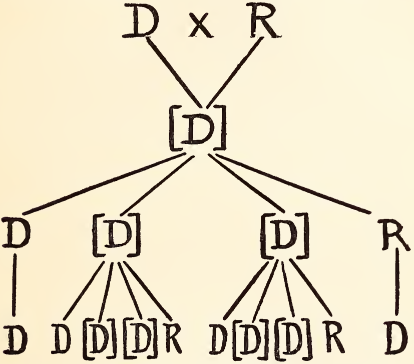


Fig. 36 —Mendelian Inheritance in Peas.

D., tall plant of pure strain; R., dwarf plant of pure strain; (D.), tall plant in which the dwarf character is latent; (D.), plants when self-fertilized produce plants in the following proportion: 1 D., 2 (D.), 1 R. (Punnett.)

spring partly dominant and partly recessive in the proportions of 3 : 1.

Mendel discovered an important set of facts, and he also suggested a theoretical interpretation—the theory of gametic segregation. As Bateson says, "The essential part of the discovery is the evidence that the germ-cells or

gametes produced by cross-bred organisms may in respect of given characters be of the pure parental types, and consequently incapable of transmitting the opposite character; that when such pure similar gametes of opposite sexes are united in fertilization, the individuals so formed and their posterity are free from all taint of the cross; that there may be, in short, perfect or almost perfect discontinuity between these germs in respect of one of each pair of opposite characters."

This law of the segregation of gametes accords well with the experimental and observed phenomena of heredity. But this brings up the question, Is there any known process by which such a segregation could be brought about during the history of the germ-cells? "Is it," says Thomson, "enough simply to say that the germ-cells are little living unities with an organization, an equilibrium of their own, and that they tend as they multiply to become more stable—namely, by separating out incompatibilities (dominant and recessive potential unit characters) and becoming the vehicle of either the one or the other? Are there differential divisions during the development of the germ-cells which lead to there being two camps of gametes which we may briefly describe as pure potential dominants and pure potential recessives? Is this not a possible expression of a struggle between the hereditary items and in line with Weismann's theory of germinal selection?"

"A more precise suggestion," says T. H. Morgan, "to which it seems too soon to attach great significance, is the fascinating hypothesis that the segregation occurs during the maturation division. If we assume that the chromosomes are the vehicles of the hereditary qualities, which seems highly probable; if we assume, further, that a particular potential unit character is contained in each germ-cell in one chromosome and not in others, which seems a difficult assumption; then it is possible that Sutton may be correct in his suggestion that the segregation of

gametes into two sets occurs in the course of the maturation division."

A great deal of work confirming Mendel's experiences has been done both with plants and animals in laboratories in many countries, with the result that altho there are some difficulties and not a few discrepancies, "the truth of the law," as Bateson says, "is now established for a large number of cases of most dissimilar character."

On the other hand, there has been much experimentation in which the results do not harmonize with the Mendelian results. Thomson says: "There seems at present no reason to believe that the Mendelian formula has more than a limited application, tho it is of course possible that apparent exceptions may eventually turn out to be less formidable than they seem. There seems no reason why there should not be several formulæ of inheritance, each applicable to particular sets of cases—*e.g.*, to cases where blending does occur and to cases where it never occurs. As the method of experiment is obviously the surest line of progress, the more it is prosecuted the sooner will the mists surrounding heredity disappear, but progress cannot be secured by ignoring difficult cases or by straining the formula in the eager desire to universalize it."

Extensive theoretical and practical applications of Mendel's law to problems of biology have been made. For the technical discussion of Mendel's law in connection with persistence in evolution and in relation to definite variations, reference must be made to some of the detailed studies on Mendelism. The following illustrations from Thomson and from Punnett will show its value to practical breeders.

Some kinds of wheat are very susceptible to the fungoid disease known as 'rust'; others are immune. The quality of immunity to rust is recessive to the quality of predisposition to rust. When an immune and a non-immune strain are crossed together the resulting hybrids are

all susceptible to 'rust.' On self-fertilization such hybrids produce seed from which appear dominant 'rusts' and recessive immune plants in the expected ratio of 3 : 1. From this simple experiment the phrase 'resistance to disease' has acquired a more precise significance, and the wide field of research here opened up in this connection promises results of the utmost practical as well as theoretical importance.

"The new science of heredity has much to teach the practical man," says Punnett. "Let us suppose that he has two varieties, each possessing a desirable character, and that he wishes to combine these characters in a third form. He must not be disappointed if he makes his cross and finds that none of the hybrids approach the ideal which he has set before himself; for if he raises a further generation he will obtain the thing which he desires. He may, for example, possess tall green-seeded and dwarf yellow-seeded peas, and may wish to raise a strain of green dwarfs. He makes his cross—and nothing but tall yellows result. At first sight he would appear to be further than ever from his end, for the hybrids differ more from the plant at which he is aiming than did either of the original parents.

"Nevertheless, if he sow the seeds of these hybrids he may look forward with confidence to the appearance of the dwarf green. And owing to the recessive nature of both greenness and dwarfness, he can be certain that for further generations the dwarf greens thus produced will come true to type. The green dwarfs are all fixed as soon as they appear, and will throw neither talls nor yellows. The less the hybrid resembles the form at which the breeder aims, the more likely is that form to breed true when it appears in the next generation.

In the years since 1900 there has been deep interest in the microscopic study of germ-cells in the search for the mechanism of heredity. Much observation and experimentation has been done and there has been a rapid ad-

vance in knowledge, but so intricate are the questions involved that investigation is most difficult and only a start at the problems has been made. In an address before the American Association for the Advancement of Science in December, 1907, E. G. Conklin well summarizes the arguments in support of the two general views under which opinions concerning the material bearers of inheritance may be said to be grouped, namely, the view that the chromosomes of the germ-cell are the bearers of heredity and the view that inheritance may take place through the cytoplasm of the germ-cells. A few of the less technical paragraphs of this paper are as follows:

"In practically all theories of heredity it is assumed that there is a specific 'inheritance material,' distinct from the general protoplasm, whose function is the 'transmission' of hereditary properties from generation to generation, and whose characteristics, as compared with the general protoplasm, are greater stability, independence and continuity. This is the Idioplasm of Nägeli, the Germ-plasm of Weismann. It is further assumed that this germ-plasm is itself composed of ultramicroscopical units, which are capable of undergoing transformation during the course of development into the structures of the adult. However necessary such units may be for a complete philosophical explanation of development, it must be confessed that at present they constitute a purely hypothetical system which may or may not correspond to reality. We know that the germ-cells are exceedingly complex, that they contain many visible units such as chromosomes, chromomeres and microsomes, and that with every great improvement in the microscope and in microscopical technique other structures are made visible which were invisible before, and whether the hypothetical units just named are present or not seems to be a matter of no great importance, seeing that, so far as the analysis of the microscope is able to go, there are differentiated units which

are combined into a system—in short, there is organization.

"On the other hand, the evidence in favor of an inheritance material, which is distinct from the general protoplasm of the germ and whose function is the reproduction of hereditary characters, is not convincing. All the living substance of the egg cell is converted into the mature organism. That there is a species plasm or an individual plasm which is continuous from generation to generation, and from which all the qualities of the mature organism are differentiated, is almost a certainty, but there is no satisfactory evidence that this substance is distinct from the general protoplasm of the young germ-cells.

"Differentiation, and hence heredity, consists in the main in the appearance of unlike substances in protoplasm and their localization in definite regions or cells.

"Unfortunately, we do not know many of the steps by which different substances appear within protoplasm. But in all cases which have been carefully studied one significant fact appears, viz., the importance of the interaction of the nucleus and cytoplasm. In many cases various substances have been seen to come out of the nucleus and to mingle with the cytoplasm, while the nucleus in turn absorbs substances from the cytoplasm. It is known that constructive metabolism, differentiation and regeneration never occur in the absence of a nucleus.

"Turning now to the differentiations of the fertilized egg cell, we find that different substances appear in the egg cell and become localized in different regions of the egg or embryo. It is known that there is an active interchange of nuclear and cytoplasmic substances. In the long growth period of the egg the nucleus grows enormously, evidently at the expense of substances received from the cell body. On the other hand, it is well established that substances issue from the nucleus into the cell body and mingle with the cytoplasm during this stage.

"Finally, we may conclude that the nucleus plays a less important role in the localization of different substances than in the formation of those substances. Nevertheless, in differentiation, as well as in metabolism, there is every reason to believe that the entire cell is a physiological unit. Neither the nucleus nor the cytoplasm can exist long independently of the other; differentiations are dependent upon the interaction of these two parts of the cell; the entire germ-cell, and not merely the nucleus or cytoplasm, is transformed into the embryo or larva; and it therefore seems necessary to conclude that both nucleus and cytoplasm are involved in the mechanism of heredity.

"It may be considered as definitely settled that the early development of animals is of purely maternal type, and that it is only after the broad outlines of development and the general type of differentiation have been established that the influence of the spermatozoon begins to make itself felt; and it is equally certain that this type of differentiation is predetermined in the cytoplasm of the mature egg cell rather than in the egg nucleus.

"On the other hand, there is no doubt that the differentiations of the egg cytoplasm have arisen, in the main, during the ovarian history of the egg, and as a result of the interaction of nucleus and cytoplasm; but the fact remains that at the time of fertilization the hereditary potencies of the two germ-cells are not equal, all the early development, including the polarity, symmetry, type of cleavage, and the relative positions and proportions of future organs, being predetermined in the cytoplasm of the egg-cell, while only the differentiations of later development are influenced by the sperm. In short, the egg cytoplasm fixes the type of development and the sperm and egg nuclei supply only the details.

"This conclusion is not a refutation of the nuclear inheritance theory, but it is a profound modification of it. At once it destroys the argument that since there is equality of inheritance from both parents there must be

equivalence of inheritance material in egg and sperm. So far as those characteristics are concerned which appear late in development, it is highly probable that there is equality of inheritance from both parents, but in the early and main features of development, hereditary traits, as well as material substance, are derived chiefly from the mother.

"In the light of the conclusion that only the later and more detailed differentiations are influenced by the sperm, it follows that experimental work which aims to modify the fundamental features of an organism must be directed to the ovarian egg rather than to the sperm or to the developing embryo."

In conclusion, the following paragraphs from E. B. Wilson's 'The Cell in Development and Inheritance' will indicate the present state of the cytological study of inheritance problems and the outlook for the future. "We have now arrived," he says, "at the farthest outposts of cell-research, and here we find ourselves confronted with the same unsolved problems before which the investigators of evolution have made a halt. For we must now inquire what is the guiding principle of embryological development that correlates its complex phenomena and directs them to a definite end. However we conceive the special mechanism of development, we cannot escape the conclusion that the power behind it is involved in the structure of the germ-plasm inherited from foregoing generations.

"What is the nature of this structure and how has it been acquired? To the first of these questions we have as yet no certain answer. The second question is merely the general problem of evolution stated from the standpoint of the cell-theory. The first question raises once more the old puzzle of preformation or epigenesis. The pangen-hypothesis of de Vries and Weismann recognises the fact that development is epigenetic in its external features; but, like Darwin's hypothesis of pangenesis, it is

at bottom a theory of preformation, and Weismann expresses the conviction that it is an impossibility.

"The truth is that an explanation of development is at present beyond our reach. The controversy between preformation and epigenesis has now arrived at a stage where it has little meaning apart from the general problems of physical causality. What we know is that a specific kind of living substance, derived from the parent, tends to run through a specific cycle of changes during which it transforms itself into a body like that of which it formed a part; and we are able to study with greater or less precision the mechanism by which that transformation is effected and the conditions under which it takes place. But despite all our theories, we no more know how the organization of the germ-cell involves the properties of the adult body than we know how the properties of hydrogen and oxygen involve those of water. So long as the chemist and physicist are unable to solve so simple a problem of physical causality as this, the embryologist may well be content to reserve his judgment on a problem a hundredfold more complex.

"The second question, regarding the historical origin of the idioplasm, brings us to the side of the evolutionists. The idioplasm of every species has been derived, as we must believe, by the modification of a preëxisting idioplasm through variation and the survival of the fittest. Whether these variations first arise in the idioplasm of the germ-cells, as Weismann maintains, or whether they may arise in the body-cells and then be reflected back upon the idioplasm, is a question to which the study of the cell has thus far given no certain answer. Whatever position we take on this question, the same difficulty is encountered, namely, the origin of that coordinated fitness, that power of active adjustment between internal and external relations, which, as so many eminent biological thinkers have insisted, overshadows every manifestation of life. The

nature and origin of this power is the fundamental problem of biology.

"It may be true, as Schwann himself urged, that the adaptive power of living beings differs in degree only, not in kind, from that of unorganized bodies. It is true that we may trace in organic nature long and finely graduated series leading upward from the lower to the higher forms, and we must believe that the wonderful adaptive manifestations of the more complex forms have been derived from simpler conditions through the progressive operation of natural causes. But when all these admissions are made, and when the conserving action of natural selection is in the fullest degree recognised, we cannot close our eyes to two facts: first, that we are utterly ignorant of the manner in which the idioplasm of the germ-cell can so respond to the influence of the environment as to call forth an adaptive variation; and second, that the study of the cell has on the whole seemed to widen rather than to narrow the enormous gap that separates even the lowest forms of life from the inorganic world.

"I am well aware that to many such a conclusion may appear reactionary or even to involve a renunciation of what has been regarded as the ultimate aim of biology. In reply to such a criticism, I can only express my conviction that the magnitude of the problem of development, whether ontogenetic or phylogenetic, has been underestimated; and that the progress of science is retarded rather than advanced by a premature attack upon its ultimate problems. Yet the splendid achievements of cell-research in the past twenty years stand as the promise of its possibilities for the future, and we need set no limit to its advance. To Schleiden and Schwann the present standpoint of the cell-theory might well have seemed unattainable. We cannot foretell its future triumphs, nor can we doubt that the way has already been opened to better understanding of inheritance and development."

CHAPTER XVI

ADAPTATION

ALTHO but one element of organic evolution, the origin of species, has been emphasized in the preceding pages, it has been noticed perhaps in the various discussions brought up that evolution is concerned not only with the great variety of life kinds, but also with the "adaptedness or adaptiveness of life kinds" to various sorts of life-conditions. As Kellogg phrases it, "The task of an evolution explanation is a double one; it must explain not only diversity or variety in life, but adaptive diversity or variety."

The most striking fact in nature is this adaptation of organisms to their environment. On every side plants and animals seem to be well fitted to their particular places in nature. Every organism seems to have been constructed after an ideal plan, and it is not surprising that so many observers of nature have believed that plants and animals were specially designed and created to fit the places in nature which they fill. Verworn says:

"The fact of purposefulness in living nature, which was so marvelous to men of science in early times even down to the middle of the present century, forced them constantly to embrace teleology—*i.e.*, the hypothesis of a foreordained plan of creation, such as dogmatic theology, preserving faithfully the ancient venerated ideas, accepts to-day. This purposefulness in nature is the simple ex-

pression—or, better, the result—of the adaptation of organisms to their vital conditions in the widest sense."

Thus all animals have their essential organs adapted to habitat, food and various conditions of environment. Fishes have limbs in the form of fins, which function very perfectly as rowing-organs; terrestrial vertebrates have in place of fins legs for walking and creeping upon dry land; birds have wings constructed most fittingly with which their light bodies, supported by bones containing air, soar through the air so perfectly that imitation of them is difficult.

Likewise plants are so perfectly adapted to their surroundings in the general plan and arrangement of root, stem, leaf, flower, etc., that only the special student is likely to recognise the adaptation. In fact, these general adaptations of organs and functions of plants and animals are so universal that they have ceased to excite wonder and are taken as necessary phenomena of life. They are necessary phenomena of life, for general adaptations are as natural as breathing, eating and so on.

In addition to the general adaptations to widespread conditions of environment—*e.g.*, to the general conditions under which all land animals and plants or all aquatic animals and plants must live—there are myriads of special adaptations. For example, all fishes living in fresh water have in common general adaptations to an aquatic life, but fishes living in caverns have in addition to the general adaptations certain special adaptive modifications in accordance with their special environment, especially in the eyes, which are profoundly modified in accordance with a life spent habitually in darkness. Likewise all plants living on land have a general adaptation to terrestrial life, but in addition many have special adaptations. All plants which have green leaves use them for starch formation under the action of sunlight, but special adaptations fit certain species to different degrees of light intensity, and as

a result one plant may be fitted to grow in open fields while another will grow but in shaded places.

Special adaptations have attracted much attention from students because by contrast with general adaptations they prove valuable in evolutionary studies. For the sake of convenience the special adaptations of plants and animals will be considered separately, and also color adaptations will be treated in a separate section. However, this is purely an arbitrary division, for all studies of the special adaptations of plants and animals lead to the same conclusion—namely, that these adaptations have originated through the processes of evolution.

One of the best collections of facts concerning special adaptations is to be found in the extended chapter on this subject in Jordan and Kellog's 'Evolution and Animal Life,' from which some of the most striking examples have been selected for use here.

The various types of special adaptations may be roughly divided into five classes as follows: Food-securing, self-defense, defense of young, rivalry and adjustment to surroundings.

"For the purpose of capture of their prey, most carnivorous animals are provided with strong claws, sharp teeth, hooked beaks and other structures familiar to us in the lion, tiger, dog, cat, owl and eagle. Insect-eating mammals have contrivances especially adapted for the catching of insects. The ant-eater, for example, has a long sticky tongue which it thrusts forth from its cylindrical snout deep into the recesses of the ant-hill, bringing it out with its surface covered with ants. Animals which feed on nuts are fitted with strong teeth or beaks for cracking them. Strong teeth are found in those fishes which feed on crabs or sea urchins. Those mammals like the horse and cow, that feed on plants, have usually broad chisel-like incisor teeth for cutting off the foliage, and teeth of very similar form are developed in different groups of plant-eating fishes. Molar teeth are found when it is nec-

essary that the food should be crushed or chewed, and the sharp canine teeth go with a flesh diet. The long neck of the giraffe enables it to browse on the foliage of trees in grassless regions.

"Insects like the leaf-beetles and the grasshoppers, that feed on the foliage of plants, have a pair of jaws, broad

Fig. 38 —Adaptation for Food-getting.
Head of a mosquito (female), showing the piercing, needle-like mouth parts composing the "bill." (Jordan and Kellogg.)

but sharply edged, for cutting off bits of leaves and stems. Those which take only liquid food, as the butterflies and sucking bugs, have their mouth parts modified to form a slender, hollow sucking beak or proboscis, which can be thrust into a flower nectary or into the green tissues of plants or the flesh of animals to suck up nectar or plant sap or blood, according to the special food habits of the

insect. The honey-bee has a very complicated equipment of mouth parts fitted for taking either solid food like pollen or liquid food like the nectar of flowers. The mosquito has a 'bill' composed of six sharp, slender needles for piercing and lacerating the flesh and a long tubular under lip through which the blood can flow into the mouth. Some predaceous insects, as the praying horse, have their fore legs developed into formidable grasping organs for seizing and holding their prey.

"For self-protection the higher animals depend largely on the same organs and instincts as for the securing of food. Carnivorous beasts use tooth and claw in their own defense, as well as in securing their prey, but these, as well as other animals, may protect themselves in other fashions. Many of the higher animals are provided with horns, structures useless in procuring food but effective as weapons of defense. Others defend themselves by blows with their strong hoofs. Among the reptiles and fishes and even among the mammals the defensive coat of mail is found in great variety. The crab and lobster, with claws and carapace, are well defended against their enemies, and the hermit crab, with its well-knowl habitude of thrusting its unprotected body within a cast-off shell of a sea snail, finds in this instinct a perfect defense. Insects also, especially beetles, are protected by their coats of mail. Scales and spines of many sorts serve to defend the bodies of reptiles and fishes, while feathers protect the bodies of birds and hair those of most mammals."

The ways in which animals make themselves disagreeable or dangerous to their captors are almost as varied as the animals themselves. Besides the teeth, claws and horns of ordinary attack and defense, there are found among the mammals many special structures or contrivances which serve for defense through making their possessors unpleasant.

The turtles are all protected by bony shields, and some of them, the box turtles, may close their shields almost

hermetically. The snakes broaden their heads, swell their necks or show their forked tongues to frighten their enemies. Some of them are further armed with fangs connected with a venom gland, so that to most animals their bite is deadly.

Even the fishes have many modes of self-defense through giving pain or injury to animals who would swallow them. The catfish, or horned pout, when attacked sets immovably the sharp spine of the pectoral fin, inflicting a jagged wound. Pelicans which have swallowed a catfish have been known to die of the wounds inflicted by the fish's spine. In the group of scorpion fishes and toad fishes are certain genera in which these spines are provided with poison glands. Many fishes are defended by a coat of mail or a coat of sharp spines. The globe fishes and porcupine fishes are for the most part defended by spines, but their instinct to swallow air gives them an additional safeguard. When one of these fishes is disturbed it rises to the surface, gulps air until its capacious stomach is filled and then floats, belly upward, on the water. It is thus protected from other fishes, tho easily taken by man.

The torpedo, electric eel, electric catfish and star-gazer surprise and stagger their captors by means of electric shocks. The shock is felt severely if the fish be stabbed with a knife or metallic spear. The electric eel of the rivers of Paraguay and southern Brazil is said to give severe shocks to herds of wild horses driven through the streams, and similar accounts are given of the electric catfish of the Nile. In tropical seas the tangs, or surgeon fishes, are provided with a knifelike spine on the side of the tail, the sharp edge directed forward and slipping into a sheath. This is a formidable weapon when the fish is alive.

Other fishes defend themselves by spears (swordfish, spearfish, sailfish), or by saws (sawfish, sawshark), or by paddles (paddlefish). Others still make use of sucking

disks of one sort or another (as in the snailfish, the clingfish and the goby) to cling to the under side of rocks, or as in the Remora, to the bodies of swift-moving sharks. Blind fishes in the caves are adapted to their condition. In similar circumstances salamanders, crayfishes and insects are also blind. Some fishes, as the lancelet, lie buried in the sand all their lives. Others, as the sand darter and the hinalea, bury themselves in the sand at intervals to escape from their enemies. Some fishes called the flying fishes sail through the air with a grasshopper-like motion that closely imitates true flight.

Among the insects the possession of stings is not uncommon. The wasps and bees are familiar examples of stinging insects, but many other kinds less familiar are similarly protected. All insects have their bodies covered with a coat of armor, composed of a horny substance called chitin. In some cases this chitinous coat is very thick and serves to protect them effectually. This is especially true of the beetles. Some insects are inedible and are conspicuously colored so as to be readily recognised by insectivorous birds.

The protection of the young is the source of many adaptive structures as well as of the instincts by which such structures are utilized. In general those animals are highest in development, with the best means of holding their own in the struggle for life, that take best care of their young. Those instincts which lead to home building are all adaptations for preserving the young. Among the lower or more coarsely organized birds, such as the chicken, the duck and the auk, as with the reptiles, the young animal is hatched with well-developed muscular system and sense organs and is capable of running about and, to some extent, of feeding itself. Birds of this type are known as præcocial, while the name altricial is applied to the more highly organized forms, such as the thrushes, doves and song birds generally. With these the young are hatched in a wholly helpless condition, with ineffective

muscles, deficient senses and dependent wholly upon the parent. The altricial condition demands the building of a nest, the establishment of a home and the continued care of one or both of the parents. In the Marsupials—the kangaroo, opossum, etc.—the young are born in a very immature state and are at once seized by the mother and thrust into a pouch or fold of skin along the abdomen, where they are kept until they are able to take care of themselves. This is a singular adaptation, but less specialized and less perfect than the condition found in ordinary mammals.

The movements of migratory fishes are mainly controlled by the impulse of reproduction. Many fresh-water fishes, as trout and suckers, forsake the large streams in the spring, ascending the small brooks where their young can be reared in greater safety. Still others, known as anadromous fishes, feed and mature in the sea, but ascend the rivers as the impulse of reproduction grows strong. Among such fishes are the salmon, shad, alewife, sturgeon and striped bass in American waters. Catadromous fishes, as the true eel, reverse this order, feeding in the rivers and brackish estuaries, apparently finding their usual spawning ground in the sea.

In questions of attack and defense the need of fighting animals of their own kind, as well as animals of other races, must be considered. To struggles of species with those of their own kind the term rivalry may be applied. Actual warfare is confined mainly to males in the breeding season, especially in polygamous species. Among those in which the male mates with many females, he must struggle with other males for their possession. The most notable adaptation is seen in the superior size of teeth, horns, mane or spurs. In the family of deer, buffalo and domestic sheep and cattle the male is larger and more powerfully armed than the female.

A large part of the life of the animal is a struggle with the environment itself. In this struggle only those that are

adapted live and leave descendants fitted like themselves. The fur of mammals fits them to their surroundings. As the fur differs so may the habits change. Some animals are active in winter; others, as the bear, and in northern Japan the red-faced monkey, hibernate, sleeping in caves or hollow trees or in burrows until conditions are favorable for their activity. Most snakes and lizards hibernate in cold weather. Some animals in hibernation may be frozen alive without apparent injury. As animals resist heat and cold by adaptations of structure and habits, so may they resist dryness. Certain fishes hold reservoirs of water above their gills by means of which they can breathe during short excursions from the water.

Another series of adaptations is concerned with the places chosen by animals for their homes. The fishes that live in the water have special organs for breathing under water. The hooked claws of the bat hold on to rocks, the bricks of chimneys or to the surface of hollow trees, where the bat sleeps through the day. The tree frogs or tree toads have the tips of the toes swollen, forming little pads by which they cling to the bark of trees.

Among other adaptations relating to special surroundings or conditions of life are the great cheek pouches of the pocket gophers, which carry off the soil dug up by the large shovel-like feet when the gopher excavates its burrow. Insects that live in water either come up to the surface to breathe or take down air underneath their wings, or in some other way, or have gills for breathing the air which is mixed with the water. Many fishes, chiefly of the deep seas, develop organs for producing light. These are known as luminous organs, phosphorescent organs or photophores.

While aming the higher or vertebrate animals, especially the fishes and reptiles, most remarkable cases of adaptation occur, yet the structural changes are for the most part external, usually not affecting fundamentally the development of the internal organs other than the skeleton. The

organization of these higher animals is much less plastic than that of the invertebrates. In general the higher the type the more persistent and unchangeable are those structures not immediately exposed to the influence of the struggle for existence. It is thus the outside of an animal that tells where its ancestors have lived. The inside, suffering little change whatever the surroundings, tells the real nature of the animal.

A special kind of adaptation is shown by animals which are parasitic. These animals attach themselves to the body of their prey or burrow into it, are carried about by it and live upon it. Some parasites are adapted to an external parasitic life, such as bird lice, fleas, ticks, etc.; others are adapted to an internal parasitic life, as is the case in the tapeworm and trichina.

In nearly all cases the structure of the parasite is very simple, much simpler than that of other animals which live free, active lives. This simplicity, however, is not primitive, but results from the degeneration of structures rendered useless by the habit of life. Thus a fixed and permanent parasite possesses no locomotor organs, no special sense organs, no highly developed nervous system, no alimentary system and but a very simple circulatory and respiratory system. Lankester has well expressed the effects of the parasitic habit of life: "Let the parasitic life once be secured and away go legs, jaws, eyes and ears; the active, highly gifted crab, insect or annelid may become a mere sac, absorbing nourishment and laying eggs."

This simplicity of structure in parasitic animals does not, however, indicate that they belong to animals low in the scale of animal life. It is rather the result of a mode of life. This is shown by the fact that many parasites in their young stages are free, active animals, very much more complex in structure than they are in adult life. Lankester's comparison of the life-history of the parasites Sacculina and Lernæocera with that of an active shrimp

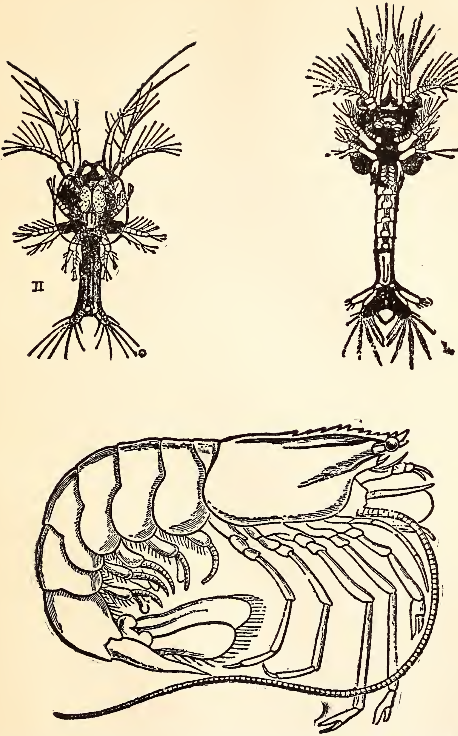


Fig. 39 —Larvæ and Adult Shrimp, Peneus; Showing Advancing Complexity. (Lankester.)

will illustrate this point. Diagrams are given, showing the advancing complexity of structure in the shrimp Peneus.

Compare these with the young stages of a number of shrimp-like animals, viz., Sacculina, Lernæocera, Lepas, Cyclops, Limnetis, some of which lead a parasitic life. The eggs of all develop equally into the recapitulative phase known as the Nauplius, but while the Nauplius of the free-living shrimp grows more and more elaborate, observe what happens to the parasites; they degenerate into comparatively simple bodies, and this is true of their internal structure as well as of their external appearance. The most utterly reduced of these parasites is the curious Sacculina, which infests hermit crabs and is a mere sac filled with eggs, and absorbing nourishment from the juices of its host by root-like processes.

Lernæocera again, which in the adult condition is found attached to the gills of fishes, has lost the well-developed legs of its Nauplius childhood and become an elongated worm-like creature fitted only to suck in nourishment and carry eggs.

In this same group the life-history of the barnacle illustrates a similar degeneration not due to parasitism. This again Lankester describes. Among these pictured Nauplii, all belonging to the great group Crustacea, which includes crabs and shrimps, is one which gives rise to an animal decidedly degenerate but not precisely parasitic in its habits. The egg of the Barnacle gives rise to an actively swimming Nauplius, the history of which is very astonishing. After swimming about for a time the Barnacle's Nauplius fixes its head against a piece of wood and takes to a perfectly fixed, immobile state of life. Its organs of touch and of sight atrophy, its legs lose their locomotor function and are simply used for bringing floating particles to the orifice of the stomach, so that an eminent naturalist has compared one of these animals to a man standing on his head and kicking his food into his mouth.

Were it not for the recapitulative phases in the develop-

ment of the Barnacle, we may doubt whether naturalists would ever have guessed that it was a degenerate Crustacean. It was, in fact, for a long time regarded as quite remote from them and placed among the snails and oysters.

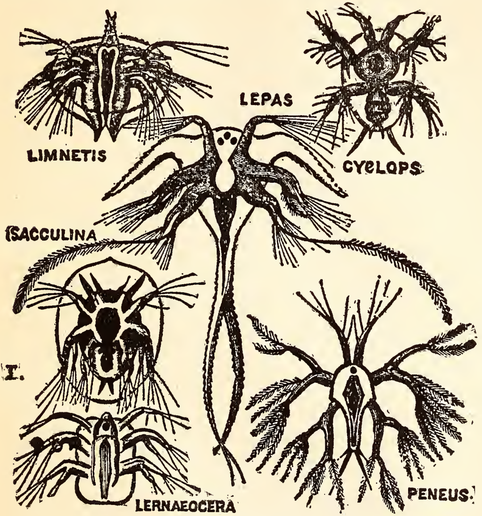


Fig. 40 —Nauplii of Various Crustacea. Shrimps, water-fleas, barnacles, etc. (Lankester.)

Its true nature was only admitted when the young form was discovered.

Very many other organisms among both plants and animals showing varying degrees of degenerative adaptation might be cited. It should be noted in this connection that

degeneration in biology means an evolutionary method of adaptation by means of which plants and animals are adjusted to special environmental conditions; it does not mean weakness, decline, defects and decay in structural and physiological conditions similar to those occurring in human life. There is only a far-fetched analogous resemblance between human degeneration in the usual sense and degeneration in biology which may be called adaptive because as a result of such degeneration organisms are better fitted for life under special conditions. In fact, many naturalists believe that natural selection has often preserved those individuals which because of certain degenerations are better fitted to their life-conditions. Hence adaptive degeneration in biology is a form of evolution, and it is a highly significant fact that some species of animals and plants have been fitted to their special environment by adaptive degeneration.

It should be noted in passing that in animals and plants there is non-adaptive and destructive degeneration that is parallel to degeneration in human life. The effects of disease in weakening and ultimately destroying animals and plants is an example. In all such cases there is no advantage gained which is exactly the case in the physiological, mental and moral degeneration commonly referred to in human life. Obviously adaptive degeneration has occurred in human life, for the human body has dozens of structures like the appendix which have been adapted by a degenerative process.

Some of the most important special plant adaptations are along these lines: nutritive adaptations, adaptations for protection against animals, adaptations for pollination, adaptations for the dispersal of fruits and seeds, and color adaptations for attracting animals. Of the nutritive adaptations the parasitic habit of life in plants which draw their food supply wholly or partially from another plant or animal, called the host, should be mentioned. The dodder shows an adaptation of this kind. It lives on the

stems of other plants, and instead of developing roots and green leaves with which to carry on the processes of food manufacture, it develops no green leaves but instead a special absorbing organ, the 'haustoria,' which penetrates the tissues of the host plant from which it obtains its nourishment. There are many plants adapted to this parasitic habit of life; others are semi-parasitic. This is the case with the mistletoe, the false foxgloves and with some orchids.

A curious case of special nutritive adaptation is to be found in carnivorous plants. These plants seem to require animal food and have organs variously modified to obtain it. In the common sundew insects are caught by a sticky secretion which proceeds from hairs on the leaves. When an insect touches one of these sticky hairs it is caught and the hairs at once begin to close over it until it is held fast on the leaf. Here it soon dies and then remains for many days, while the leaf pours out a juice by which some parts of the insect are digested. This digested material is then absorbed, while the undigested parts drop off after the hairs let go their hold. Other interesting adaptations for the capture by plants of insects are to be found in the Venus fly trap, the common pitcher plant and others.

Other modifications have been developed as a means of protection from vegetable-feeding creatures. These are chiefly along the lines of the formation of uneatable tissue, as in the horsetails and rushes, the arming of exposed parts with cutting edges, stinging hairs, prickles and thorns, as in grasses, nettles, cactuses, etc., and the accumulation of disagreeable or poisonous substances in exposed parts, as in the tansy, ragweed, boneset, jimson weed and poisonous hemlock. One of the acacias (Acacia sphærocephala) has an interesting adaptation to attract ant dwellers as a protection from insects and other creatures. At the bases of the leaves there are developed large hollow stipules and at the ends of the leaflets are nectaries. The ants bore holes in the stipules, live in them, find food in the nectaries

and offer valuable protection to the plant in warding off its enemies. A large number of plants offer inducements of many sorts to attract ant visitors.

The special adaptations for the dispersal of seeds offer an equally interesting field for study. It is obviously of advantage to the plant that its seeds be disseminated as widely as possible. Sometimes the seeds themselves are

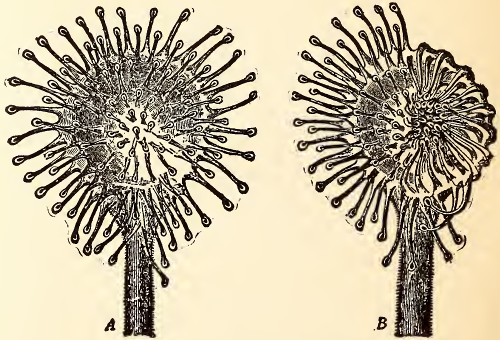


Fig. 41 —Two Leaves of a Sundew.

In A. the glandulæ hairs are fully extended; in B. they are bent inward in the position they assume when an insect has been caught. (Kerner.)

modified for dispersal, sometimes the fruit in which they are enclosed and often it is a larger part of the plant. This is the case with the common tumbleweed, a profusely branching plant bearing many seeds which in the fall is torn from its anchorage by the wind and rolled about, scattering its seeds for great distances. Some fruits which are distributed by the wind are provided with wings, as in the maple, elm, ash, etc., while others bear plumes

Wound Parasite Growing on Bark of Tree.

and feathery tufts to enable them to float in the air, as in the dandelions, thistles and others.

Not infrequently the adaptation for seed dispersal is in the mechanical discharge provided for in the structure of the seed-case. In such plants as the witch hazel, violet, wild balsam and others the dry fruits burst with explosive

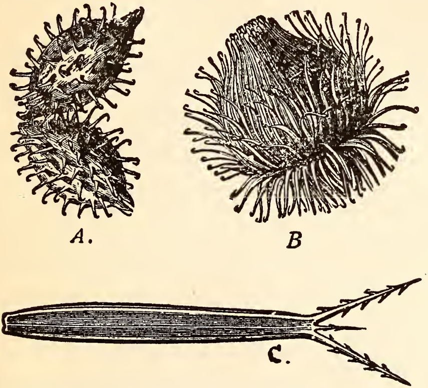


Fig. 42 —Seeds Adapted for Dispersal by Animals. A., Cockle-bur; B., Burdock; C., Spanish Needles. (Kerner.)

force, throwing the seeds some distance away from the parent plant.

When the adaptations are related to dispersal by means of animals they take the form of grappling appendages, as in the beggar ticks, stick tights, burdocks, cockleburs, etc., of hard seeds capable of passing through the digestive tract unharmed or of attractive and brightly colored fruits whose seeds are undesirable or indigestible. Good examples of conspicuously colored fruits whose seeds are scat-

tered in this way are cherries, raspberries, blackberries, etc.

It will be noted that the color adaptations of plants referred to so far are supposed to relate plants to animals. But aside from these, there are many general and special adaptations in coloring substances, green, yellow and red, which have a physiological value in plant life. These, however, are special problems of botany and cannot be referred to here.

The whole question of color adaptations in plants has in recent years come up for rediscussion. This discussion cannot be given here, but a good idea of the points at issue can be gathered from the perusal of an essay entitled 'The Significance of Color' by Professor D. T. MacDougal, of the Carnegie Institute.

In discussing the color adaptations of animals, it is convenient to group them in the following classes: Protective and aggressive resemblances; warning coloration; mimicry and colors displayed in courtship.

The color pattern of animals is often such as to effectuall conceal them in their surroundings. Thus tree-dwelling animals are often green in color, as is the case with the tree-frog; desert dwellers are often a mottled gray, while arctic dwellers are a snowy white. Far more striking, however, than these cases of general color adaptation are those cases of special adaptation in which the animal resembles in color and shape some particular part of its usual environment. Professors Jordan and Kellogg, in 'Animal Life,' give some good example of special color adaptation. Among them are the following:

The larvæ of the geometrid moths, called inch-worms or span-worms, are twig-like in appearance and have the habit, when disturbed, of standing out stiffly from the twig or branch upon which they rest, so as to resemble in position as well as in color and markings a short or a broken twig. One of the most striking resemblances of this sort is shown by a large geometrid larva found near

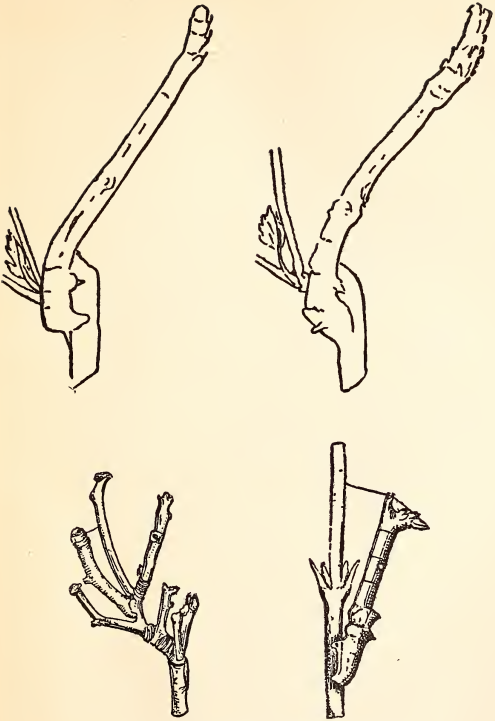


Fig. 43 —Protective Resemblance.
Larvae of geometrid moths concealed by their resemblance to twigs. (Poulton.)

Ithaca, New York. The body of this caterpillar has a few small, irregular spots or humps, resembling very exactly the scars left by fallen buds or twigs. These caterpillars have a special muscular development to enable them to hold themselves rigidly for long times in this trying atti-

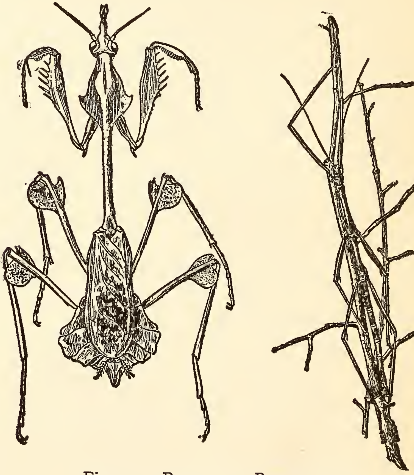


Fig. 44 —Protective Resemblance.
A 'leaf' insect. A 'walking-stick' insect.

tude. They also lack the middle prop-legs of the body common to other lepidopterous larvæ, the presence of which would tend to destroy the illusion so successfully carried out by them. The common walking-stick, with its wingless, greatly elongate, dull-colored body, is an excellent example of special protective resemblance. It is quite

indistinguishable, when at rest, from the twigs to which it is clinging. Another member of the family of insects to which the walking-stick belongs is the famous green-leaf insect. It is found in South America and is of a bright green color, with broad leaf-like wings and body, with markings which imitate the leaf veins and small irregular yellowish spots which mimic decaying, or stained, or fungus-covered spots in the leaf.

There are many butterflies that resemble dead leaves. But most remarkable of all is a large butterfly (Kallima) of the East Indian region. The upper sides of the wings are dark, with purplish and orange markings, not at all resembling a dead leaf. But the butterflies when at rest hold their wings together over the back, so that only the under sides of the wings are exposed. The under sides of Kallima's wings are exactly the color of a dead and dried leaf, and the wings are so held that all combine to mimic with extraordinary fidelity a dead leaf still attached to the twig by a short pedicle or leaf-stalk imitated by a short tail on the hind wings and showing mid-rib, oblique veins, and, most remarkable of all, two apparent holes, like those made in leaves by insects, but in the butterfly imitated by two small circular spots free from scales and hence clear and transparent. With the head and feelers concealed beneath the wings, it makes the resemblance wonderfully exact. In all cases of this kind the animals are said to be protectively colored.

Special color resemblance sometimes does more than conceal an animal from its enemies; it often assists it to catch its prey. Such animals are said to be aggressively colored or to have aggressive resemblance. The colors of snakes, lizards and frogs are doubtless both protective and aggressive, while those of the polar bear, the arctic fox, the weasel, the wolf, the lion and the tiger are purely aggressive. Poulton, in 'The Colors of Animals,' cites some examples of a still more remarkable use of color resemblance. He says:

"Special Aggressive Resemblance sometimes does more than hide an animal from its prey; it may even attract the latter by simulating the appearance of some object which is of special interest or value to it. Such appearances have been called Alluring Coloration by Wallace, and they are some of the most interesting of all forms of Aggressive Resemblance.

"An Asiatic lizard, Phrynocephalus mystaceus, is a good example. Its general surface resembles the sand on which it is found, while the fold of skin at each angle of the mouth is of a red color and is produced into a flower-like shape exactly resembling a little red flower which grows in the sand. Insects, attracted by what they believe to be flowers, approach the mouth of the lizard, and are of course captured.

"The Angler, or Fishing Frog, possesses a lure in shape of long, slender filaments, the foremost and longest of which has a flattened and divided extremity. The fish stirs up the mud so as to conceal itself and waves these filaments about. Small fish are attracted by the lure, mistaking it for worms writhing about in the muddy waters; they approach and are instantly engulfed in the enormous mouth of the Angler.

"An Indian Mantis (Hymenopus bicornis) feeds upon other insects which it attracts by its flower-like shape and pink color. The apparent petals are the flattened legs of the insect."

While many animals are very inconspicuously colored, or are manifestly colored so as to resemble their surroundings, generally or specifically, many other animals are very brightly and conspicuously colored and patterned. They possess warning coloration. "A very common example of an animal with warning colors," says Poulton, "is afforded by the larva of the Currant Moth or Magpie Moth, which is excessively abundant in gardens. The caterpillar is extremely conspicuous, being of a cream color, with orange and black markings. Altho it belongs to the group of well-

concealed 'stick-caterpillars,' it makes no attempt to hold itself in any of the attitudes characteristic of its group. All observers agree that birds, lizards, frogs and spiders either refuse this species altogether or exhibit signs of the most intense disgust after tasting it."

The caterpillar of the Buff-tip Moth and the Cinnabar Moth are also extremely abundant and are good examples of the association of Warning Colors with a nauseous taste. Both of them are gregarious, living in large companies, so that their conspicuous appearance is greatly in-

Fig. 45 —Warning Coloration.
A salamander, showing gaudy coloring.

tensified. The colors of the first-named larva are black, yellow and orange. It feeds on oak, elm, lime, birch, hazel, etc., and the large bare branches which attest its appetite are very familiar sights in autumn. The second caterpillar is colored by alternate black and yellow rings; it feeds upon ragwort in the summer. There is plenty of experimental evidence for the unpleasant taste of both caterplilars.

The conspicuously black-and-yellow banded larva of the common Monarch butterfly is a good example of the possession of warning colors by distasteful caterpillars.

These warning colors are possessed not only by the ill-tasting caterpillars but by many animals which have spe-

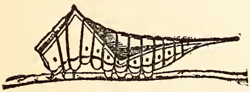
cial means of defense. The wasps and bees, provided with stings—dangerous animals to trouble—are almost all conspicuously marked with yellow and black. The lady-bird beetles, composing a whole family of small beetles which are all ill-tasting, are brightly and conspicuously colored and spotted. The Gila Monster, the only poisonous lizard, differs from most other lizards in being strikingly patterned with black and brown. Some of the venomous snakes are conspicuously colored, as the coral snakes or coralillos of the tropics.

All these animals with warning colors are described as possessing some quality, a disagreeable taste or odor, stings, hairs, etc., causing them to be obnoxious to other animals that might seize them for food. Poulton says: "The object of warning colors is to assist the education of enemies, enabling them to easily learn and remember the animals which are to be avoided."

Another special kind of color adaptation to be included under Warning Coloration is known under the head of recognition markings. Instead of attracting the attention of enemies, these markings are of use in attracting the attention of individuals of the same species. To this category belong the white upturned tail of the rabbit, the black tip of the weasel's tail and many of the bright feathers in wings and tail displayed by birds in flight.

Certain animals which are without special means of defense and are not at all formidable or dangerous are yet so marked or shaped and so behave as to present a threatening or 'Terrifying Appearance.' The large green caterpillars of the Sphinx moths—the tomato-worm is a familiar one of these larvæ—have a formidable-looking, sharp horn on the back of the next to last body ring. When disturbed they lift the hinder part of the body, bearing the horn, and move it about threateningly. As a matter of fact, the horn is not at all a weapon of defense, but is quite harmless. The larvæ of the Puss moth has been often referred to as a striking ex-

ample of terrifying appearances. When one of these larvæ is disturbed "it retracts its head into the first body ring inflating the margin, which is of bright red color. There are two intensely black spots on this margin in the appropriate position for eyes, and the whole appearance is that of a large flat face extending to the outer edge of the red margin. The effect is an intensely exaggerated caricature of a vertebrate face, which is probably alarming to the vertebrate enemies of the caterpillar. . . . The effect is greatly strengthened by two pink whips which are swiftly protruded from the prongs of the fork in which the body terminates . . . The end of the body is at the same time curved forward over the back, so that the pink filaments are brandished above the head."



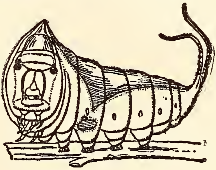


Fig. 46 —Defensive Mimicry. Durva of puss moth, showing terrifying attitude when disturbed.

Some of the instances of protective resemblance, warning coloration and "terrifying attitudes" that have been given are sufficiently remarkable, but the phenomena of mimicry are even more surprising. The term mimicry has been reserved for those cases in which an otherwise defenseless animal, one without poison, fang or sting, and without an ill-tasting substance in its body, mimics some other specially defended or inedible animal sufficiently to be taken for it and so escape attack. These instances are especially to be observed among insects. The most familiar example perhaps is that of the Viceroy butterfly, which mimics the Monarch.

The bees and wasps are protected by their stings. They are usually conspicuous, being banded with yellow and

black. They are mimicked by numerous other insects, especially moths and flies, two defenseless kinds of insects. This mimicking of bees and wasps by flies is very common, and can be observed readily at any flowering shrub. The flower-flies (Syrphidæ), which, with the bees, visit flowers, can be distinguished from the bees only by sharp observing. When these bees and flies can be caught and examined in hand it will be found that the flies have but two wings while the bees have four.

In addition to the colors and patterns which assist an animal to evade or warn off its enemies or to secure its prey there are also colors and appendages which must have some very different meaning. These appearances are seen in mature animals, and frequently undergo periodical development at times which correspond to the breeding season; and when the two sexes differ, the males are almost invariably the more brilliant. Instances in which the colors of the males exceed those of the females in brilliancy or pattern are many among fishes, lizards, birds, spiders, insects, etc. It is most common among insects and birds. Many of these sexual differences were described in the chapter on Sexual Selection.

However these colors may have arisen, every observer must admit that they are in some way connected with sex. Darwin accounted for them by his celebrated theory of 'Sexual Selection.' He supposed that the esthetic sense is widely distributed among the higher animals (vertebrates and some of the most specialized invertebrates), and that the colors, which certainly appeal to this sense in man, are not without effect in causing gratification to the animals themselves. This explanation of the origin and meaning of sexual coloring is not accepted by Mr. Wallace, whose chief objection is the lack of evidence that the female has any esthetic preferences at all in the selection of her mate.

Concerning the whole question of the adaptations of plants and animals there is much question to-day. It is

thought by many that the strength of the natural selection explanation rests on the logical nature of its premises and conclusions rather than on scientific observation and experiment. By others it is thought to be the best explanation so far advanced. Professor Kellogg comments on the present status of the theory in its relation to adaptations as follows: "There is no gainsaying to the selection explanation its claim to stand among all proposed explanations of adaptation as that one least shaken by the critical attack of its adversaries. However mightily the scientific imagination must exert itself to deliver certain difficult cases into the hands of selection, and however sophisticated and lawyer-like the argument from the selection side may be for any single refractory example, the fact remains that the selectionist seems to be able to stretch his explanation to fit all adaptations, with less danger of finding it brought up against positive adverse facts than is possible to the champion of any other so far proposed explanation."

So comprehensive is the doctrine of evolution that it has been described as "one of the greatest acquisitions of human knowledge." Professor Locy writes of it: "There has been no point of intellectual vantage reached which is more inspiring. It is so comprehensive that it enters into all realms of thought." Weismann expresses the opinion that "the theory of descent is the most progressive step that has been taken in the development of human knowledge," and further he says that this opinion "is justified even by this fact alone: that the evolution idea is not merely a new light on the special regions of biological sciences, zoölogy and botany, but is of quite general importance. The conception of an evolution of life upon the earth reaches far beyond the bounds of any single science and influences our whole realm of thought. It means nothing less than the elimination of the miraculous from our knowledge of nature, and the placing of the phenomena of life on the same plane as the other natural

processes; that is, as having been brought about by the same forces and being subject to the same laws."

Already the field of evolution is being still further extended by new problems in human evolution. The evidences in reference to the evolution of the human body are so conclusive that it is generally accepted that the natural continuity of life includes the human species, and students are turning their attention to the problem of the evolution of mentality. In Professor Locy's words: "The progressive intelligence of animals is shown to depend upon the structure of the brain and the nervous system, and there exists such a finely graded series in this respect that there is strong evidence of the derivation of human faculties from brute faculties."

The conception of evolution is no new idea—it is the human idea of history grown larger, large enough to cover the whole world. The extension of the idea was gradual as men felt the need of extending it; and at the same moment we find men believing in the external permanence of one set of phenomena, in the creation of others, in the evolution of others. One authority says human institutions have been evolved; man was created; the heavens are eternal. According to another, matter and motion are eternal; life was created; the rest has been evolved, except, perhaps, the evolution theory which was created by Darwin.

Of the wise men of Greece and what they thought of the nature and origin of things little will be said. Most of them were philosophers, not naturalists, and we are apt to read our own ideas into their words. They thought, indeed, about the physical and organic universe, and some of them believed it to be, as we do, the result of a process; but here in most cases ends the resemblance between their thought and that of modern students.

Thus when Anaximander spoke of a fish-like stage in the past history of man, this was no prophecy of the modern idea that a fish-like form was one of the far-off

ancestors of backboned animals; it was only a fancy invented to get over a difficulty connected with the infancy of the first human being.

Or, when several of these sages reduced the world to one element, the ether, it is doing the progress of knowledge an injustice to say that men are simply returning to this after more than two thousand years. For that conception of the ether which is characteristic of modern physical science has been, or is being, slowly attained by precise and patient analysis, whereas the ancient conception was reached by metaphysical speculation. If a return is being made to the Greeks it is on a higher turn of the spiral, so far at least as the ether is concerned.

When Empedocles sought to explain the world as the result of two principles—love and hate—working on the four elements one may, if so inclined, call these principles "attractive and repulsive forces"; he may recognise in them the altruistic and individualistic factors in organic evolution and what-not; but Empedocles was a poetic philosopher, no far-sighted prophet of evolution.

As in other departments of knowledge, so in biology the work of Aristotle is fundamental. It is wonderful to think of his knowledge of forms and ways of life, or the insight with which he foresaw such useful distinctions as that betwen analogous and homologous organs, or his recognition of the fact of correlation, of the advantages of division of labor within organisms, of the gradual differentiation observed in development. He planted seeds which grew after long sleep into comparative anatomy and classification. Yet with what sublime humility he says: "I found no basis prepared, no models to copy. Mine is the first step, and therfeore a small one, though worked out with much thought and hard labor."

Aristotle was not an evolutionist, for altho he recognised the changefulness of life, the world was to him an eternal fact, not a stage in a process.

"In nature the passage for inanimate things to

animals is so gradual that it is impossible to draw a hard-and-fast line between them. After inanimate things come plants, which differ from one another in the degree of life which they possess. Compared with inert bodies, plants seem endowed with life; compared with animals, they seem inanimate. From plants to animals the passage is by no means sudden or abrupt; one finds living things in the sea about which there is doubt whether they be animals or plants."

Among the Romans Lucretius gave noble expression to the philosophy of Epicurus. He was a cosmic, but hardly an organic evolutionist, for according to his poetic fancy organisms arose from the earth's fertile bosom and not by the gradual transformation of simpler predecessors.

"In the first place, the first breed of lions and the savage races their courage has protected, foxes their craft, and stags their proneness to flight. But light-sleeping dogs with faithful heart in breast, and every kind which is born of the seed of beasts of burden, and at the same time the woolly flocks and the horned herds, are all consigned to the protection of man. For they have ever fled with eagerness from wild beasts, and have ensued peace, and plenty of food obtained without their own labor, as we give it in requital of their useful services. But those to whom nature has granted none of these qualities, so that they could neither live by their own means nor perform for us any useful service, in return for which we should suffer their kind to feed and be safe under our protection, those, you are to know, would lie exposed as a prey and booty of others, hampered all in their own death-bringing shackles, until nature brought that kind to utter destruction."

From Lucretius to Buffon the intervening centuries were uneventful as regards zoölogy. Hugo Spitzer, one of the historians of evolution, finds analogies between

certain medieval scholastics and the Darwinians of the nineteenth century, but these are subtle comparisons. Yet long before Darwin's day there were evolutionists, and the first of these who can be called great was Buffon.

One must guard against supposing that the works of Buffon, or Lamarck, or Darwin were inexplicable creations of genius, or that they came like cataclysms, without warning, to shatter the conventional traditions of their time. For all great workers have their forerunners, who prepare their paths. Therefore in thinking out the history of evolutionist theories before that of Buffon account must be taken of many forces which began to be influential from the twelfth century onward. "Evolution in social affairs has not only suggested our ideas of evolution in the other sciences, but has deeply colored them in accordance with the particular phase of social evolution current at the time." The evolution of theories of evolution is bound up with the whole progress of the world.

Among the evolutionists before Darwin only three need be noted—Buffon, Erasmus Darwin and Lamarck. Buffon (1707-1788) was born to wealth and was wedded to Fortune. As Director of the Jardin du Roi he had opportunity to acquire a wide knowledge of animals. He commanded the assistance of able collaborateurs, and his own industry was untiring. He was about forty years old when he began his great Natural History, and he worked till he was fourscore. He lived a full life, the success of which we can almost read in the strong confidence of his style.

Erasmus Darwin (1731-1802), grandfather to the author of the Origin of Species, was a large-hearted, thoughtful physician, whose life was as full of pleasant eccentricities as his stammering speech of wit and his books of wisdom. Buffon underrated the transforming influence of action, and laid emphasis upon the direct influence of surroundings; Erasmus Darwin emphasized function, and re-

garded the influence of the environment as for the most part indirect.

On Lamarck (1744-1829) success did not shine as it did on the Comte de Buffon or on Dr. Erasmus Darwin. His life was often so hard that it is wonder he did not say more about the struggle for existence.

Of Lamarck's Philosophie Zoölogique Haeckel says: "This admirable work is the first connected and thoroly logical exposition of the theory of descent." And again he says: "To Lamarck will remain the immortal glory of having for the first time established the theory of descent as an independent scientific generalization of the first order, as the foundation of the whole of Biology."

The condition of evolution is variability, or the tendency which animals have to change. The primary factors of evolution are those which produce variations, which cause organic inequilibrium.

There are evidently three direct ways in which these organic changes may be produced: (1) From the nature of the organism itself—*i.e.*, from constitutional or germinal peculiarities which are ultimately traceable to influences from without; (2) from changes in its functions or activity—in other words, from use and disuse; or (3) from the direct influence of the external conditions of life—food, temperature, moisture, etc.

It is with such problems as these that modern research into the causes of the descent of species is concerned. But of these to-day scientists are forced to confess almost complete ignorance. As for the future, the keynote of work is to examine life at closer range and from new points of view, to observe life phenomena with a keener and more critical eye, to evolve new methods of work, to experiment more extensively, more intensively and more critically, to classify, to organize and to deduce. And with patient, careful and long-continued effort who will say that even these mysteries may not yield up their secrets for the benefit of mankind?